MEGHNAD SAHA

S. B. KARMOHAPATRO

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S.B. KARMOHAPATRO

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'Free thinking is good

but right thinking is better'

Meghnad Saha,
April 3, 1939.

To my sons
Phalguni and Santanu
who share my interests
in science writing.

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PREFACE

This book is the saga of a man, who was born in a lower middle class family of a remote Indian village but became a legendary personality in his life time through his extraordinary achievements in the field of science and unparallel patriotism in promoting social consequences of science for his motherland. This book does not pretend to be a definitive biography of this great personality whose scientific pursuits ranged from Astrophysics to Atomic Nucleus and whose outlook and action as an organiser and planner laid the foundation of Modern India. This book is a modest attempt to give an account of the man, highlighting his scientific concepts which were so much a part of him. Science was so central to his being that his activities on promoting social awareness of science were always influenced by his scientific outlook.

This book narrates his life story in such a way that the reader can understand the essence of the man, his science, his character as a rebel and his time covering the last period of the British rule and first few years of our Independence, during which he made extraordinary contributions to science and to the development of the country.

The book is intended for general reader and hence narration of his science is presented here in a simplified manner by excluding mathematical explanations and jargons but not over-simplified to appear trivial.

Topics of his scientific papers, enlisted in this book, reveal that Saha with his creative and versatile genius made many important

contributions in different branches of physics. A few contributions of Saha are so fundamental in nature that they will continue to influence the world of science for centuries to come. In assessing his candidature for the Fellowship of the Royal Society of London in 1927, the Council of the Society found that some of Saha's papers had 225 citations, highest of all the candidates in that year.

Articles and addresses of Saha appearing in this book are not exhaustive. For the full list with the text, readers may refer to his collected works.

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I remember, with gratitude the suggestions, advice and inspiration given by Ajit Kumar Saha (now deceased) in writing this book on the life and works of his illustrious father.

I also thankfully acknowledge the assistance and encouragement of Shri Bibekananda Ray, Additional Director (News) of the All India Radio in preparing the manuscript.

I am grateful to Dr Jayant Vishnu Narlikar for reading the manuscript carefully and making suggestions to improve the text. In spite of all efforts, any error that might have crept in the text is due to the inadvertance of the author and none else.

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I

INTRODUCTION

This book unfolds the story of a self-made and extremely simple man, a scientist and a rebel. The simplicity of Saha made him almost austere but his outstanding scientific contributions to the theory of thermal ionisation and its application to solar and stellar spectra revolutionised the world of science. Arthur Stanley Eddington, while discussing the topic on stars in the Encyclopaedia Britannica described the said theory of Saha as the twelfth most important landmark in the progress of astronomy since the first variable star (Mira Ceti) was discovered by Fabricus in 1596. S. Rosseland wrote in the Introduction on his book *Theoretical Astrophysics*..... "The impetus given to Astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field have been influenced by it and much of the subsequent work has the character of refinements of Saha's ideas."

In fact, the subject of Astrophysics emerged in a cognizable shape with the said contribution, where Saha applied his knowledge of atomic physics, developed in the context of quantum theory by Bohr, to the observations in optical astronomy.

His lifelong mission was to improve the state of scientific education and research work in India as well as to promote social awareness of science in the country. He also fought against the ignorance, poverty, and superstitions prevailing in the society at that time.

Before proceeding further , we may take a cursory look at the social, political and research atmosphere of the country in the last decade of the nineteenth century when Saha was born. This will help

us in appreciating the background in which Saha continued his researches independently without any help or guidance from here or abroad and how he acquired fame in his later life.

Saha was born, when India was under the British rule. The Indian National Congress under the leadership of Mahatma Gandhi was initiating a non-violent movement against the British rule and on the other hand, the revolutionary parties were taking recourse to violence and terrorism for the same purpose. This was the period when fabric of Indian society was riddled with various problems like religions, fanaticism, casteism and the like.

English education, not to speak of science education was out of the reach of the common people. In undivided Bengal, demands for English education were gaining ground since 1823 A.D., when Rammohan Roy submitted a memorandum in this regard to the then Viceroy Lord Amherst. The rulers paid no heed to it. However earlier in 1784, an Englishman, William Jones, a great scholar and Indologist founded the Asiatic Society of Bengal on his own, to study the history and archeology of Asia as well as to study its science, literature, art and crafts and the relation of its people to its natural environment. Many renowned Indian scholars, enrolled as members of this society, could do some research work under its auspices, thus initiating a modest but ambitious scientific research tradition in this country.

From the middle of the nineteenth century, the British Government in their own interest set up a few English schools and colleges to train Indians for recruiting some of them to the lower cadres in the administration. However, some of these institutions could impart a very high standard of education. One such institution was Calcutta Medical College which was established in 1835. Mahendra Lal Sarkar, one of the students of this college, felt for the first time, the importance of science in the uplift of the country.

The other two institutions in Calcutta were the Presidency college and St. Xavier's Jesuit school. In the latter father La Font was a popular physics teacher, who by his lectures and discussions, could kindle science consciousness in the Indian society.

Mahendra Lal Sarkar passed from the medical college but earned fame as a Homeopathy practitioner. From 1868 onward, he published the *Calcutta Journal of Medicine* which paved the way for the general readers to communicate their independent scientific views and thoughts. In one of its issues he published a plan to establish the Indian Association for Cultivation of Science, where Indians would be able to carry on scientific researches of high standard at par with those of the west.

It was founded in 1876. C.V. Raman working in this institution was elected a Fellow of the Royal Society of London in 1924 for his contributions on sound waves. Because of Raman's work, Indian Association earned world wide fame when he won the nobel prize in physics for 1927 for his famous contribution, 'Raman Effect'; the experiment was performed in the laboratory of the Association.

In fact, J.C. Bose was the first Indian to earn international reputation for his researches on the polarisation of electro magnetic waves. Results of these works were published in the journals of the Asiatic Society and the Royal Society, London. In 1875, he succeeded in microwave communication, recognised as a pioneering work in radiophysics. In 1900 he shifted his interest to explore the similarity in response to biotic and abiotic entities. Researches on this line were important in the contemporary science and it is some times mentioned that his researches laid the foundation of the subject 'Cybernatics'.

Sir Asutosh Mukherjee founded the Science College under the Calcutta University for awarding post-graduate degree in science,

where C.V. Raman was appointed the first Professor in Physics and Prafulla Chandra Ray in Chemistry. Prafulla Chandra was a D.Sc. from Edinburg and earned fame by the discovery of mercurous nitrite compound and was a pioneer in founding chemical industries in India.

Jagdis Chandra and Prafulla Chandra were the pioneers of scientific researches in India in the nineteenth century. C.V. Raman and other two scientists Saha and Satyen Bose were worthy successors to them. Satyen Bose for his 'Bose Statistics' and Saha for his theory of thermal ionisation earned international repute as pioneers of theoretical physics in India. At a later period Saha combined both theory and experiment as the field of his research. Contemporary scientific research was greatly influenced by Raman, Saha, Jagdis Chandra, P.C. Ray and Satyen Bose although initially their scientific explorations were confined to undivided Bengal. Mahendra Lal Sarkar, William Jones and Asutosh Mukherjee were mainly responsible for building the infrastructure for continuing such outstanding scientific researches in India.

Some other states of India were also progressing in this direction. Elphinstone College of Bombay was such a centre of learning, imparting education of high standard. Gradually more luminaries in the field of science and technology were being produced from outside Bengal. Later H.J. Bhabha from Bombay, a Ph. D. from Cambridge University, renowned the world over for Bhabha Heitler theory in cosmic ray physics, took a lead in atomic energy researches in India as the Chairman of Atomic Energy Commission and the Secretary, Department of the Atomic Energy, Govt. of India. Atomic Research Centre at Trombay, now named after him and a number of establishments under the Department of Atomic Energy, combined together, show the results of enormous scientific activities of Bhabha, who planned and built the framework of a large scientific enterprise in India.

Vikram Sarabhai, a cosmic ray physicist and an industrialist appointed as Bhabha's successor (after his untimely death in 1966) took the Atomic Energy programme to the high level Bhabha had dreamt of. He, for the first time, established a close link between science and industry in India. Apart from his significant contributions in cosmic ray physics, he initiated the space research programme in this country. Today, both the atomic energy and space research programmes of India are considered to be at par with those of some developed countries of the world.

It may be mentioned here that Calcutta was the seat of teaching and research in nuclear physics and its credit goes to Dr Saha. He was the one who set up a 4 MeV cyclotron project in the forties at Calcutta. With great difficulty he collected resources to build up the first Nuclear Physics laboratory in India. He had plans to set up an Electron Synchrotron and a Research Reactor in his laboratory. In a series of articles in *Science and Culture* during 1947-54, Dr Saha was the first person in India to explain the great potentiality of atomic energy and urgency of its utilisation for peaceful purposes. Dr Saha was a member of the Atomic Energy Committee of India formed in 1947 with Dr Bhabha as the Chairman and Dr Krishnan and Dr Bhatnagar as other members. Dr Saha had probably hoped that the future Indian Atomic establishment would grow up around his laboratory as the nucleus.

But it turned out otherwise due to the decision of the then Prime Minister Pandit Nehru. Bhaba was made the chief of the Atomic Energy programmes with Bombay as its centre.

Meanwhile Dr S.S. Bhatnagar, a renowned scientist of Saha's time, as the Secretary of Scientific Research, Government of India, made a significant contribution by planning and establishing a chain of National Laboratories in India under the banner of Council of Scientific and Industrial Research.

Saha met Bhatnagar first in London in 1919 and soon they came close to each other. Their friendship grew through their common interest of promoting social awareness of science in India.

Prime Minister Jawaharlal Nehru patronised Bhatnagar in setting up the chain of National Laboratories with an aim to link scientific research with industry.

The prominent role played by Bhatnagar in the development of science and technology in India may be well assessed from a glowing tribute paid to the memory of late Dr S.S. Bhatnagar by Jawaharlal Nehru, in his inaugural address at the 42nd session of the Indian Science Congress held at Baroda in 1955. Nehru observed, "I have always been associated with many prominent figures and among the chief was Dr S.S. Bhatnagar. It is not necessary to say anything formal about him. You all knew him. But I would like to pay a tribute to Dr Bhatnagar with whom, I had co-operated for the last six, seven years or more, and, who I think, has done, I say this with all respect due to others, more than any one else for the scientific development in India. We have eminent scientists in this country and people eminent in other ways; Dr Bhatnagar was a special combination of many things added to which was a tremendous energy, with an enthusiasm to achieve things. The result was, he has left a record of achievements which is truly remarkable. I can truly say that but for Dr Bhatnagar, you could not have seen today the chain of National Laboratories in India."

During 1939-47, Saha through his articles in *Science and Culture* preset the stage for emergence of scientific and industrial research in India. He analysed the details of the British prototype, the D.S.I.R. and the National Research Council of Canada and focussed attention on the need for establishing similar organisations in the

country for scientific and industrial research.

However, Saha as an influential member of the Governing body of the Council of Scientific and Industrial Research wholeheartedly co-operated with Bhatnagar. Bhatnagar used to give due importance to Saha's advice on several occasions. His advice was decisive in establishing a National Laboratory for research on special technological areas including its location and choice of Director.

In the foregoing context of the scientific scenario of the country, we recall the life and works of Meghnad Saha who not only contributed significantly to the Astrophysics and Physics of Ionosphere but to other fields as well like Atomic and Nuclear physics. In unfolding the story we shall see how he organised other fields of research like, Biophysics, Solid State physics, Nuclear chemistry, Theoretical Nuclear physics etc. He was a pioneer in introducing Big Science in India with a 4 MeV cyclotron project at Calcutta.

He promoted the social awareness of science by his ideas, solutions of emerging problems and organisational ability. Some of these are:

(i) Organisation of scientific and industrial research,

(ii) Atomic energy and its industrial use;

(iii) Foundation and development of Indian Science Academies, Societies and Associations.

(iv) Setting up of the Indian Association for Cultivation of Science;

(v) River Valley Development Projects;

(vi) Planning the National Economy,

(vii) Educational reforms and elevation of the standards of scientific research; and

(viii) Modification of the Indian Calendar.

Besides his original research papers numbering about 88 which were published as a collection by the Council of the Scientific and Industrial Research, New Delhi, he wrote nearly 200 articles on the above topics in *Science and Culture* and various other journals by which attention was drawn to these problems with proposed solutions by Saha. His endeavors succeeded to a large extent as is reflected in the present development of science and technology in India.

He entered the Indian parliament in 1952 by election as an independent candidate which was welcomed by J.B.S. Haldane from the University College of London. Haldane in a message on the sixtieth birthday of Saha congratulated him for his outstanding contributions in science. He also mentioned 'May I also be allowed to congratulate him on his recent successful re-entry into politics. India (and Britain too) needs men who will bring some understanding of science to the government of the country. Even those who do not share his political views may rejoice that he can make his voice heard in the council of the people'.

Jawaharlal Nehru in his inaugural address of the 49th session of the Indian Science Congress held in 1962 at Cuttack referred to the new convictions of Vinoba Bhave which he admitted to have impressed his mind and the conviction, he referred to, is as follows: "He (Bhave) has been saying that politics and religion are out of date and they should be replaced by science and spirituality.....".

This conviction was partly true in the life of Saha long before. Science was his politics all along his life. The motivation behind his

entry into the Indian Parliament was to promote science and its social awareness instead of any other political ideology. He was a Hindu by religion but he was indifferent to any religious rituals. In fact, he was secular in the true sense of the word but he had a profound knowledge of scriptures and Indian philosophy. His spirituality was based on his own philosophy of life aimed at the single ideal i.e. to raise the standard of living of his countrymen.

Saha's life was rather obscure to us till 1954, when his sixtieth birthday celebration committee published a compilation on his life and work. The said compilation could be his 'Autobiographical notes' if narrated in first person, since the Editor in the foreword submits 'The account of Professor Saha's life and work given in this volume is mostly based on materials and notes received from him'. It is also mentioned that some aspects of his activities, included in that volume, were written by him, at the request of the committee.

In addition, his creative thoughts expressed in large number of articles published in *Science and Culture* and elsewhere show how they have influenced the future development of science and technology in the country.

Saha's conviction that our universities be given larger grants to enable them to revitalise their research activities is still relevant today. As envisaged by Saha the importance of industrialisation of the country is now realised and Khadi movement has little significance today in the development of the nation.

Saha's plans and analysis on the river valley projects are still relevent to the existing and the proposed projects at various sites.

Teaching of nuclear physics and the Post-M.Sc. courses, introduced now in the Indian universities and the research institutes, follow the pattern which was set up by Saha long before.

The variable Energy Cyclotron at Calcutta and the proposed High Energy Accelerator at Indore reflect his vision of Big Science, which Saha introduced through the installation of a Cyclotron at Calcutta.

Saha's proposal to set up an Astronomical observatory in India has now materialised with the establishment of a few Astronomical observatories and institutions at Kavalur, Pune, Bangalore and Kodaikanal.

Saha's vision is mostly materialised by the advancement of Science and Technology in India during the last four decades after the demise of Saha, but his mission to elevate the living condition of the fellow countrymen through the promotion of social consequences of science is yet to be fulfilled.

II

EARLY DAYS

MEGHNAD Saha was born at a critical time in the history of India. It was the time when elite class of the country was growing more and more conscious of the atrocities of the British rule. Khadi movement was gaining ground amongst the common people even in the rural areas. A distaste for the foreign products was increasing day by day.

In spite of these upsurges, most of the villages were quiet with their simple living and backwardness in education. However, East Bengal then included in Bengal and now known as Bangladesh was more advanced in western education than its western counterpart, now known as West Bengal in India. Such advancement was centered round its major city Dacca. The southern part of Dacca i.e. Vikrampur area was more advanced in learning than the northern part, where Saha was born in Seoratali village. The village was at a distance of about 30 miles to the north of Dacca.

That he was born on October 6, 1893 was not well-known, till his sixtieth birth anniversary, which was celebrated by his colleagues and students in 1954. Meghnad Saha was the fifth child of his parents Bhubaneswari Saha and Jagannath Saha, who belonged to a Hindu middle class Baisya family. Jagannath had to maintain his family with a meagre income derived from a shopkeeping business.

Meghnad Saha was born in the night when rain with thunder-storm was raging in the sky. The thatched roof of the cottage where they lived, was trembling in cyclonic wind, when the child opened his

eyes after birth. The child was named by his grandmother 'Meghnath', nicknamed as 'Megha' perhaps as a reminder of the rough weather prevailing at the time of his birth. Customarily, the middle name 'Nath' was in match with that of his eldest brother, Jaynath, who was thirteen years older than him and the second brother Bijoynath. However, the name was somehow changed to Meghnad. May be he did not like the name Meghnath or he adopted the name Meghnad who was one of his favourite characters in *Meghnad Badh Kavya* written by Michael Madhusudan Dutt. However, when the name was changed is not definitely known. Of course, the future activities of Meghnad Saha suggests that the name befitted him most, because of its similarity with Meghnad of the myth. The only difference was that Meghnad of the Ramayana was against the deities, while this Meghnad fought against the backwardness and illiteracy of his country without any compromise against the odds till his death.

The area comprising Seoratali and its adjoining villages was prone to heavy floods in the rainy season and a boat was essential for communication even from one house to another. Though in lighter vein it is said that the children here learn to swim before they are able to walk, it is true that people in that area use to learn swimming from the very childhood. Meghnad was no exception. He was healthy like other boys, could swim and row in his early age.

Education at the primary school level was well known to the village, where there was an established primary school. Beyond that level a family could afford education to a boy, only if the family was affluent or if the boy was meritorius enough to win a scholarship.

It was a setback for Jagannath Saha that his eldest son Jaynath could not succeed in the final Entrance examination and joined a jute company on a meagre salary. His second son had to leave the school

to help his father in shopkeeping. It was destined that Meghnad would follow the same path, at least, this was determined by his father.

When the child, at the age of seven, joined the primary school, his father wished that the primary education would be essential for his son for his shopkeeping business. But the child impressed his teachers so much with his sharp memory and merit that they were eager to see the boy continue higher education after passing the primary school examination. The boy had a strong aptitude for learning. After the primary education, the real hurdle for Meghnad came in. The first and foremost was the reluctance of his father for further education of Meghnad. The reason was obvious. Jagannath had neither a liking for higher education for his sons nor had he the resources to support such education. Moreover, there was no high school near the village except a middle school teaching English at village Simulia, about seven miles from Seoratali.

Jaynath wished to support the educational expenses of Meghnad with his meagre income. But it was quite inadequate for the boarding and lodging of Meghnad in a hostel. Eager to see his younger brother to have proper education, Jaynath could find a gentleman, named Ananta Kumar Das in Simulia, who agreed to provide Meghnad with free boarding and lodging in his house on the conditions that the boy would attend to some minor household chores of his family.

However, Meghnad gladly accepted the above condition, since it gave him an opportunity to continue his studies further. The gratitude of Meghnad to Mr Das and his family knew no bounds. Even in the later period of his prosperity and affluence, Meghnad used to remember with gratitude the kindness of Mr Das and his family in providing him shelter without which he would not be able to pursue his studies.

At the Simulia middle school, Meghnad had some excellent teachers, one of whom was Mr Prasanna Kumar Chakraborty. He acknowledged with gratitude at a later time the personal attention of Mr Chakraborty given to him in teaching mathematics which founded a strong base of the subject for his career.

Meghnad stood first in the Dacca district in the Middle school examination and was awarded a scholarship.

At the age of twelve, he was admitted to the Dacca Collegiate school, where he got Nikhil Ranjan Sen and Surendra Kumar Roy as his classmates. At a later period Nikhil Ranjan Sen was renowned for his contributions in applied mathematics and became the Ghosh professor of applied mathematics at the Calcutta University. Professor Sen, after the demise of Meghnad Saha, founded the Indian Astronomical Society at Calcutta in 1959 with the founder members like professors F. Goreux, P.L. Bhatnagar, P.C. Vaidya, V.B. Anand and Satyendra Nath Bose along with many others of scientific repute. Surendra Kumar Roy later on became a professor of Electrical Engineering and the Superintendent of the College of Engineering and Technology at Jadavpur.

When in Simulia, Meghnad used to visit his native village on foot in weekends. From Dacca it was not possible for him to do so. He could go home only in the summer and puja holidays. At home during the holidays, he used to help his father in grazing the cattle and taking them to bathe. Along with other domestic chores, he always assisted his younger brother in his studies.

Meghnad's scholarship was not adequate for his maintenance at Dacca. His elder brother helped him with a meagre amount from his salary. The Purba Banga Baisya Samity of his community granted him a small amount monthly. These added together amounted

to a sum which could be spent by him for his bare necessities like food and lodging.

He had to remain barefooted even in the school as he could not always afford money to buy a pair of shoes for himself. His bare foot was soon a curse for him. In the same year of his admission to the Dacca Collegiate School, the freedom movement of the country took a new turn against the proclamation of the then Viceroy Lord Curzon to affect the partition of Bengal. Student community of Bengal rebelled against this forced partition.

Dacca was no exception. The senior students of the Collegiate School staged a boycott of the visit of the then Governor of Bengal Sir Bamfylde Fuller to the School. Nikhil Ranjan Sen, Meghnad and many other youngsters were arrested. The barefoot of Meghnad was taken as a deliberate insult to the revered guest. All of them were expelled from the school. Meghnad now faced an insurmountable hurdle by losing the school and his scholarship.

Fortunately, the authorities of a private school—Kishori Lal Jubilee high school—accepted Meghnad with a free studentship and a stipend. This cleared the hurdles on the way of Meghnad to finish his school education.

Meanwhile, he joined the free Bible classes conducted by the Dacca Baptist mission. The mission used to conduct competitive examinations of Bible from time to time, which would include all the categories of students even from colleges. In one such examination, Meghnad ranked first and received a cash prize of 100 rupees with a nicely printed and bound volume of Bible.

Who could guess at that time that a school boy ranking first in a Bible examination amongst many boys of the schools and colleges of the city, could lose faith in religion in future?

This paradox is difficult to resolve! But, we shall come across more paradoxes later on. Meghnad not belonging to a right caste, was not allowed once to stand on the dais where the idol of Saraswati was being worshipped. It was a heart breaking incident for Meghnad, who was most blessed by the same goddess. This might be a turning point in his life leading to his apathy to any religious rituals. It is more paradoxical that in his later life, Meghnad acquired a deep knowledge of the scriptures of almost all the prominent religions.

However, Meghnad was against the caste system and the curse of untouchability in the society. In this context he respected the activities of Mahatma Gandhi. In the mess he was not allowed to enter the kitchen and touch the cooked food. He was given the task of washing all the dishes and utensils. Of course there were many of his upper caste classmates and friends who were also against this sort of discrimination.

How Meghnad respected Mahatma Gandhi is seen from the fact that he invited and organised the visit of Mahatma Gandhi to the Science College campus for addressing the young students, by the end of August 1946, when Mahatma Gandhi on his way to Noakhali, stopped for a couple of days in Rajabazar near Science College. In spite of heavy rainfall that day, Meghnad took great pains to make the meeting a success.

But it is again paradoxical that at a later period Meghnad did not support the Gandhian way of economic planning of the country through the advancement of the spinning wheel and the Khadi movement. Meghnad strongly pleaded for a fast emergence of the modern industrial revolution for the economic uplift of the country.

Meghnad ranked first amongst the students appearing from East Bengal in the entrance examination held in 1909. The influence of his teachers in the school was largely responsible for building his

outstanding career. The most distinguished amongst them was Probodh Chandra Sengupta, who created in Meghnad a keen interest in the subjects like astronomy, mathematics and chronology. These interests grew further through his self-study, which was the greatest virtue in the life of Meghnad. This virtue led him to make significant contributions at a later period, securing for him international repute in the world of science.

Till 1911, Meghnad was in Dacca continuing his intermediate Science education in the Dacca College. He met here notable teachers like B.N. Das in physics, N.C. Ghosh and K.P. Basu in mathematics, H. Saha and E.C. Watson in chemistry. Principal W.J. Archibold was his English teacher. Meghnad took private lessons in German language from Dr N. N. Sen, who lived in Vienna for some time for his Ph. D. work. Meghnad had German lenguage as the fourth subject in intermediate classes.

Meghnad stood third in the Intermediate examination, scoring highest marks in mathematics and chemistry but his relatively low marks in the fourth subject i.e. German language, prevented his topping the list. Except Calcutta, the colleges outside had no laboratory facilities or provision for the students to take a fourth subject. For competing with Calcutta students Meghnad chose a language like German to be his fourth subject. This, of course, could not fulfil his desire of securing the first position in the Calcutta University.

However, his knowledge of German proved to be useful in studying the scientific journals published from Germany. In addition, his knowledge of German language helped him in his formative period to self-study the special and general theory of Relativity of Albert Einstein and he could write a popular version of the subject, on invitation, in the *Statesman* published from Calcutta. In 1919, because of his knowledge of German language, he could translate the

papers on Relativity of Einstein which were then published by Calcutta University. The brilliant trio of the contemporary Bengal namely Meghnad Saha, Satyen Bose and Prasanta Mahalanobis were involved in writing the Monograph. Satyen bose was not only the co-author of the book, but also secured the permission from Einstein for its publication in India inspite of the objections from 'Methuen', to whom Einstein already gave his sole rights of publication of his papers. Mahalanobis wrote the preface of the said volume. Satyen Bose was the classmate of Meghnad and Prasanta Mahalanobis was senior to them by one year in the Presidency College.

Throughout his life Meghnad loved his native village, his brothers and cousins and he was an obedient son of his parents. Meghnad remembered them with profound respect in later years. He founded the Bhubaneswari girls school in Seoratali in the name of his mother Bhubaneswari, who, once went to the extent of pawning her gold bangles for payment of his examination fees. This shows his deep attachment with the people of his native village. Later on, there was also a boy's high school in Seoratali founded by the villagers on their own.

In 1984, professor Ajit Saha, (now deceased) the eldest son of Meghnad Saha visited Bangladesh with his family on an invitation from the Bangladesh Government on the occasion of a seminar held in Dacca. They were overwhelmed to see how his father, still then, was held in a high esteem and honour in the eyes of their citizens. Students of different schools came in procession with posters to greet them; a proposal was put forward to associate the name of Meghnad Saha with the high school where he studied.

It is also gratifying that the native house of Meghnad is still inhabited by his other family members. His paternal shop is being run by one of his family members in Seoratali.

In 1911, Meghnad was admitted to the Presidency College at Calcutta for the B. Sc. course with honours in mathematics. Principal Archibold of Dacca College was impressed with the talents of Meghnad and regretted not having him in his own college.

At Calcutta, a new world was opened to young Meghnad. A galaxy of bright students were in his class in the Presidency College. He met here Satyen Bose and his old classmate at Dacca, Nikhil Ranjan Sen. Two other bright luminaries of future India namely Nilratan Dhar, two years senior to Meghnad and Subhas Chandra Bose, junior to him by three years, were the best friends of Meghnad.

Notable persons like J.C. Bose and P.C. Ray were teachers in the Presidency College at his time. Meghnad respected P.C. Ray not only as an extraordinary teacher but for his many other qualities like patriotism, his love for countrymen and his deep attachment to his village like his own.

In 1913, P.C. Ray accompanied his students including Meghnad for relief work in the area devastated by Damodar river floods. The flood was an eye opener in the sense that he for the first time became conscious about the social consequences of science. He envisaged the River Valley Development projects in a later period based on his earlier practical experiences in course of the relief works with Dr Ray and on other occasions.

The Presidency College had always been the source of inspiration for the students of the country for its great tradition in the history of education in India. It had a real attraction for the students of other states, too. On the eve of the inauguration of the 175th anniversary of the Presidency college on March 15, 1993, President Dr Shanker Dayal Sharma stressed the college's long tradition of academic activities. He also revealed that he had a strong desire to

get admitted to that College in his young age. He regretted that some how his desire could not be fulfilled. However, the first President of India, Dr Rajendra Prasad was a student of the Presidency College and was eight years senior to Meghnad. He was the resident of the Eden Hindu hostel in his student life and later often used to visit the hostel on invitation to preside over the social functions organised there. Rajendra Prasad was then practising law at Calcutta. Meghnad, as a boarder of the same hostel, soon made acquaintance with Rajendra Prasad.

As a boarder of the Eden Hindu hostel, he was, however, facing humiliation forced upon him by the upper caste students, who went to an extent of not allowing him to dine with them. Once he was not allowed to enter the premises where the Saraswati puja was being held. Meghnad vehemently protested against these actions. A group of conscientious students under the leadership of Jnan Chandra Ghosh, a classmate of Meghnad, left the hostel with Meghnad in protest and set up a mess at 110, College Street. Nilaratan Dhar later on joined them. Meghnad now took this opportunity to bring his youngest brother Kanailal from his native village to stay with him in the mess for pursuing his studies at Calcutta. The stipend obtained by Meghnad was not sufficient for both of them. So, he took a few private tutions for earning some extra amount. Though he loved to coach the students, it was a hard-ship too. He had to travel on a bicycle daily from north to south of Calcutta to teach his students.

Meghnad was, by nature, a rebel. He was acquainted with Pulin Das, a revolutionary, when he was a college student in Dacca. At Calcutta, as a student, he was more involved with the activities of Pulin Das and Bagha Jatin. He was even a member of the Anusilan Samiti organised by Pulin Das. Jatin used to stay at his college street mess whenever he visited Calcutta. In spite of his sympathies

towards the terrorist movement for freedom, Meghnad could not give any active support to it. Meghnad decided not to involve in active politics and wished to join some service for improving the financial condition of his family. His decision was always based on his pragmatic approach and not on his sentiments. In his later life, he used to talk about Pulin Das with admiration. Once he showed one of his students the place on lower Circular Road, where Bagha Jatin lived for some time. In 1946, he was disappointed with the failure of the revolutionary movement of India. It was during that time when he once detected a revolver and few cartidges in the drawer of a student, he remarked, ''INA movement has failed and days of individual patriots like Khudiram, Bagha Jatin and others are no longer relevant''.

Meghnad secured first division but stood second in both the B.Sc. and M.Sc. in mixed Mathematics examinations of the Calcutta University while Satyen Bose topped the list. Though a strong rivalry existed between Saha and Bose throughout their career, they were all along good friends.

The decision of Meghnad to leave politics for the sake of his family was right but by then it was late for he was not permitted to sit for the Indian Finance service, because of his association with the revolutionary parties.

Meghnad was now compelled to give up hopes of securing a Government service. To him the only alternative was to seek a job of teaching and to pursue scientific researche.

In 1946, Sir Asutosh Mukherjee, the Vice Chancellor of Calcutta University took the bold step to start M.Sc. teaching and research in physics, chemistry and mathematics in the University. Sir Taraknath Palit and Sir Rashbehari Ghosh, two eminent lawyers of

Calcutta donated substantial amount enabling Sir Asutosh to set up the University College of Science at 92, Upper Circular Road now known as Acharya Prafulla Chandra Road. Both Meghnad Saha and S.N. Bose were appointed lecturers in mathematics where Saha used to teach hydrostatics and the figure of the earth.

Very soon, it appeared that both Saha and Bose could not pull on well with Professor Ganesh Prasad, the Head of the Applied Mathematics department. Asutosh transferred them to the Physics department as lecturers, though they had studied physics up to B.Sc. pass level only. As a lecturer in Physics from 1917, he could get a good start in his life, since in those days a teaching job was not easily available. Facilities for continuing research on any subject were rare in India.

However, with this start, Meghnad could become a successful teacher and scientist in his life. The key to his success was his habit of self-study, which helped him to acquaint himself with the quantum theory, the special theory of relativity and partly with the general theory. His knowledge of German was a boon for him, since the literature on relativity was mostly in that language.

He had already acquired profound knowdedge in classical physics by self-study during his student life. His studies on the recent developments in physics now added a new dimension to his excellence in teaching physics in M.Sc. classes.

In 1918, he got married to Radharani Saha, belonging, to an affluent family of his native locality. In spite of the objections from the grand mother of Radharani to give her in marriage to a shopkeeper's son, her father did not pay heed to any excuse and settled the marriage. His plea was that Meghnad, a jewel of his society, would

be the most suitable groom for her daughter. In protest, the grandmother absented herself from home on the day of marriage.

Meghnad had earlier experience of facing the discriminatory attitude of the upper caste Hindus. Now he realized how discriminations are introduced between the haves and have nots of the same caste. However, their married life was extremely happy.

Meghnad could not forget the remarks of the grandmother of his wife. Later, in Allahabad he brought her from the village and hosted her for some days in his house. During her stay, Meghnad took her on pilgrimage to the nearby places in his own car. The grandma was very happy and blessed her grand daughter with wishes for a better future. Saha jokingly told the grandma 'Are you now convinced that by marrying me, your grand daughter has not fallen in deep waters'. The old lady replied promptly, ''you have no credit for it, all good fortune attained by you is due to the good luck of our daughter."

Later, while narrating the above conversations in an East Bengal dialect Saha used to burst out in laughter.

Meanwhile, in 1918 Saha was awarded the D.Sc. degree of Calcutta University on the reports of Professor O.W. Richardson, Dr Porter and Dr N.R. Campbell who examined his thesis. Next year Meghnad was awarded the Premchand Raychand Studentship of the Calcutta University. All these achievements were based on his research papers published since 1917, the year of his entry in the physics department, as a lecturer.

In 1920, Meghnad was awarded the Griffith prize of the Calcutta University. During the fruitful years of 1917-20, young Meghnad passed through the years from his research studentship to

a recognised scientist and an extraordinary teacher. Very soon he entered the arena of International Science through this transition.

III

THE TEACHER AND THE SCIENTIST

With the endowments of Palit and Ghosh, Sir Asutosh Mukherjee, the then Vice Chanceller of the Calcutta University, instituted Professorships in the name of Ghosh and Palit for the departments of physics, chemistry and mathematics. Ganesh Prasad was the first Ghosh Professor in applied mathematics. In 1914, Debendra Mohan Basu was appointed the Ghosh professor in physics. Unfortunately, he was interned in Germany for four years due to the first world war. So the entire load of teaching and researches was laid upon Meghnad Saha and S.N. Bose as lecturers. In organising the M.Sc. teaching in physics and setting up the laboratories for the practical classes, they took help of their colleagues such as P.N. Ghosh and S.K. Mitra.

In 1918 Sir Asutosh persuaded C.V. Raman, then in the Finance Service and carrying on part-time research in the Indian Association for Cultivation of Science, to accept the Palit Professorship in physics. He joined in the same year. However, Raman did not transfer his research laboratory from the Indian Association to the Science College and used to take only M.Sc. classes regularly. He was, of course, an extraordinary and popular teacher in the physics department.

Saha had to teach heat and thermodynamics in the M.Sc. classes, since nobody would take up these subjects. Saha, primarily not expert in these subjects, utilised the well equipped library of the Presidency College to update his knowledge in these subjects. In

addition to the studies in classical physics, he turned to the modern concepts in physics, then undergoing radical changces due to the emergence of quantum theory and relativity. The team of the physics department modernised the M.Sc. course with these new concepts. Saha had to prepare lecture notes on heat and thermodynamics with sincere and hard efforts.

In 1982, the nobel laureate S. Chandrasekhar wrote in the volume "30 years of Saha Institute of Nuclear Physics" on Meghnad Saha as follows:

'Meghnad Saha's place in the history of astrophysics and in the history of modern science in India is unique; and there are others, more competent than I, who can, who have, written amply on these matters. But there is one aspect of Saha's life to which I have not seen any reference but which has moved me.

It is that, already in 1919, only three years after the founding of the general theory of relativity, Saha and S.N. Bose should have taken the time and the effort to translate and publish Einstein's papers which have since become epochal. At a celebration of the Einstein Centennial at Princeton University, three years ago, reference was made to a Japanese translation of Einstein's papers as the first on record and I was glad that I was able to correct the impression. A xerox copy of the Saha-Bose translation is now in the Einstein Archives at Princeton.'

It is an astonishing fact that the vitality of the Indian Renaissance during the twenty year period — 1910-1930 — was such that it includes so many names which we all hold in reverence—Tagore, Ramanujan, Saha, Bose, Ray and Raman—not to mention the great names of the Indian National Movement.

It may be mentioned here that around 1920-1935, when epoch-making discoveries in physics and astrophysics were being made,

four major discoveries were made by the Indians. In 1920, thermal ionisation theory of Saha; in 1925, Bose Statistics; in 1928, the Raman effect; around 1934, the Chandrasekhar limit were the important land marks in the history of science. All these discoveries were from India, except that of Chandrasekhar, who was a Ph.D. student in England. It is, however, said that the ideas of his discovery grew in his mind, when he was a student of the Presidency College in Madras. It is a different story that Chandrasekhar won the Nobel prize for Physics in 1983 for the work he did in his twenties. However, he was elected a Fellow of the Royal Society (London) in 1944, a rare honour for an Indian-born scienist. Saha had this honour in 1927. It may be mentioned that Saha was older than Chandrasekhar by 17 years. Both got the FRS at the age of 34, but Saha's election was delayed by 2 years due to an adverse report on his connection with the Indian revolutionaries.

Before Saha earned a world wide repute through his thermal ionistion theory, he had a number of publications to his credit. His first research paper was 'On Maxwell's stresses' where it was shown that the stresses cannot account for the energy of electrification, if the medium is to be regarded as an elastic solid. It was published in the *Philosophical Magazine* of London in the year he was appointed lecturer of the physics department. The subsequent papers published in foreign and Indian journals show his ingenous efforts to solve problems in contemporary physics. They include the originality of the ideas of Saha in the areas of electro-magentic theory, electrodynamics, quantum theory and the special theory of relativity.

The paper "On the Influence of the Finite Volume of Molecules on the Equation of State" by Saha and S.N. Bose published in *Philosophical Magazine* (1918) gives a new equation of State which was an improvement on those of Dieterici, Clausius or D. Berthelot. Saha in his paper' 'On the Fundamental Law of Electrical Action',

published in *Philosophical Magazine* (1919) gave a simple deduction of the Lienard Wiechert potential due to a moving charged particle'. In a preliminary note 'On Radiation pressure and the quantum theory' published in *Astrophysical Journal* (1919), Saha tried to prove the radiation pressure on gaseous atoms which follows as an easy deduction from modern theories of emission and absorption. He also suggested that the action of light pressure is selective. He applied these ideas to explain the high velocity of solar red prominences and the mechanism of the formation of the tail of a comet.

A larger paper following the above preliminary note and entitled 'On Selective Radiation Pressure and its Applications' communicated to the *Astrophysical Journal* for publication was never published, but kept locked in a drawer at the Yerkes Observatory. In this paper Saha had put forward some of his original ideas on the effect of selective radiation pressure on steller atmospheres. Later, those ideas were developed in details by E.A. Milne of Oxford, who, of course acknowledged the contributions of Saha contained in his preliminary report published earlier. Meanwhile, Saha published a paper on 'Selective Radiation Pressure and the Radiative Equilibrium of the Solar Atmosphere' in the Journal of Department of Science, Calcutta University (1920), where he showed that the theory of Selective Radiation pressure along with the modern theories of atomic structure, is capable of explaining many problems in solar and steller physics, particularly the problems of the radiative equilibrium of the solar atmosphere, proposed by Eddington in his theory on 'Radiative Equilibrium in the interior of a star'. This being locally published could not receive much notice.

After a long time, when Saha visited the Yerkes Observatory, Dr Morgan handed him over the manuscript of the larger paper

communicated to the *Astrophysical Journal* in 1919. Why the said paper was not processed by the Editor is known from Saha's letter to Plasket, where he states that a large amount in foreign currency was demanded as a part of the printing cost because of its large volume. Saha could not afford such expenses from India. Saha did not confine his researches to theory only. He had a deep faith in the dictum of Hamilton that 'Theory and Experimental Investigations are the two eyes of physics, and research work flourish best, where workers can see with both eyes'. Saha often quoted a particular stanza from *Rasendra Chintamani* a Sanskrit text of about ninth Century. His teacher P.C. Ray in the Presidency College also often quoted the same in his classes. The gist of the quotation is as follows:

"Only by listening to what the scholars have said or reading from the books, I do not write any thing which I have not experimented myself. I have written here the results, which I derived by experiments by my own hand before my teachers. The real teachers can show his pupils by experiments, what they teach. Real pupils learning from their teachers can perform the same experiments or can improve on them".

The importance of the said dictum of the ancient India declined in the course of time. In the emergence of western science in India J.C. Bose and P.C. Ray developed their research laboratories in the Presidency College for their own work. In the science college, the facilities for experimental physics did hardly exist except the laboratories for practical classes for the M.Sc. students.

But Saha took the initiative to devise an apparatus for measuring the pressure of light, predicted by Maxwell in his electromagnetic theory of light. The prediction was earlier experimentally verified by Lebedev in 1900 and by Nichols and Hull in 1902 without any conclusive results. Saha with his ingenuous effort improved arrangement of the apparatus, got rid of the undesirable effects and

verified the predictions in an unambiguous way. Considering the suppositions and assumptions made in the theoretical calculations, he asserted that the agreement between the upper limit of the total theoretical pressure of light and the experimental values determined by him, was at least qualitatively quite good.

The said paper entitled 'On the pressure of Light' by Saha and Chakraborty which was published in the Calcutta based Journal of Asiatic Society of Bengal could not draw the proper attention of the scientific community at large.

The above papers were included in the D.Sc. thesis of Saha and his dissertation for Premchand Roychand studentship was based on an unpublished paper 'On the Harvard classification of Steller Spectra', communicated to *Philosophical Magazine*. He was awarded the Griffith prize of the Calcutta University in 1920 on his essay on origin of lines in steller spectra. The money obtained through the above awards, the Ghosh Travelling Fellowship of the Calcutta University and the help of the Brahmo Education Society at Calcutta, enabled Saha to take a trip to Europe in September, 1919, and he sailed by the Scindia Line Steamer 'Loyalty'. P.C. Ray, Jivraj Mehta, Nirmal Sidhanta, B.S. Guha and K.C. Mehta were his co-passengers in the Steamer, who later on obtained high distinction in their respective fields.

Meanwhile Saha communicated his four papers namely 'Ionisation of the solar chromosphere, 'On Elements of the Sun', 'On the problems of Temparature-Radiation of Gases' and 'On the Harvard classification of stars' to the *Philosophical Magazine*, the first of which, containing his famous thermal ionisation theory, was published when he reached U.K. All the above four papers were the foundations of his celebrated works on astrophysics and for which he became famous in the world of Science. In 1921, an introduction and the synopsis of these papers entitled 'On Electron Chemistry and

its application to problems of Radiation and Astrophysics' were published in the Journal of Astronomical Society of India (now extinct).

In teaching physics to M.Sc. classes, Saha with his habits of self-study went through the popular books on astronomy and astrophysics written by Agnes Clerk. These were the sources of his inspiration in astrophysical research. He was also conversant with the thermodynamics of Max Planck, a German text of Nernst, quantum theoretical models of Bohr and Sommerfeld and many other research papers associated with these lines of thought.

He was introduced to the scientific world through his earlier papers on the properties of electromagnetic waves, theory of electrons, electrodynamics and others. His first step towards research in astrophysics was his work on the selective radiation pressure.

As mentioned earlier his paper on 'Ionisation of the solar chromosphere' was published in the *Philosophical Magazine* before he reached Europe. The said paper contained his celebrated theory of thermal ionisation for which he earned a world wide reputation.

One of Saha's classmates, Snehamoy Datta, working in the Imperial College of Science and Technology, suggested to him to seek an interview with Professor A. Fowler of the same college, who earlier worked as an assistant to Sir Normal Lockyer, one of the pioneers in spectroscopy and astrophysics. Saha did do so. Fowler showed keen interest in Saha's work and welcomed him to work in his laboratory. Fowler rightly pointed out to him that Lockyer had studied the steller spectra in details which was systematised by Pickering and Cannon at the Harvard College observatory. Fowler, too, equipped Saha with the data and his store of knowledge in steller

spectra ungrudgingly. This induced Saha to withdraw his paper 'On the Harvard classification of Steller Spectra', from the *Philosophical Magazine* for revising and updating it based on the data supplied by Fowler. The paper rewritten by Saha was now retitled by Fowler as 'On a Physical Theory of Steller Spectra' and was communicated to the Proceedings of the Royal Society, London, by him. It was published in 1921. In this paper he utilised his theory of thermal ionisation in corroborating Russell's view that the continuous variation of steller spectral types is mainly due to the varying values of the temperature of the steller atmosphere, and the classification O,B,A, F,G,K,M, which had been adopted by the Harvard astrophysicists, as the result of long years of study and observation, was therefore seen to acquire a new physical significance. Both the papers 'Ionisation of the solar chromosphere' and 'On a Physical Theory of Steller Spectra' were the most notable contributions in astrophysics, which are said to be one of the ten most important discoveries in astronomy after Gallileo turned his telescope to the sky.

From his self study, Saha became interested in the problems of the solar chromosphere about a hypothetical levitative force, assumed to act selectively on certain atoms like those of calcium and does not act in others. In his preliminary paper 'On selective Radiation Pressure', he had deduced the existence of pressure of light based on the quantum theory of radiation and had pointed out how it would act in a selective manner on different atoms. Further elaboration of the idea in a paper communicated to the Astrophysical Journal for publication, was not published as mentioned before, and was returned to Saha by Morgan.

The background of the Saha's thermal Ionisation theory lies in the earlier theory of internal constitution of stars by Eddington, where he assumed that at high temperature in the interior of stars, atoms must have been deprived of most of their electrons. But the

question raised on how such ionisation takes place, remained unanswered for long. John Eggert, an assistant of Nernst of Berlin tried to justify such ionisation on the basis of the law of reaction isochore. He used the ionisation energy derived from this law and energies for multiple ionization were barely hypothetical. Saha felt that it was unnecessary to assume such approximate values of ionization energy, as it could be obtained from analysis of spectra of elements or from the experimental values obtained by Franck and Hertz and others, which lent an experimental foundation to Bohr's quantum theoretical model of atomic structure.

With his knowledge of thermodynamics and the study of Nernst's *Das Neue Warmesatz* containing ideas on chemical constants, he formulated the theory of thermal ionization based on Bohr's atomic model. He applied it successfully to the solar atmosphere and could explain the disappearance of spark lines in the solar atmosphere as an effect of reduction of pressure. That was the subject of his paper 'On Ionization of the solar chromosphere'. It may be mentioned here that Lockyer in his laboratory could demonstrate the differences in arc and spark spectra. The results could not be explained so far. Saha's theory could now explain the physical significance of such differences.

It was known at a later period that Saha forestalled Lindermann of Oxford and Kramers of Lieden University, to whom this problem was suggested by the personalities like Bohr and Tolman in those days.

To summarise the scientific contributions of Saha, it will be useful to outline the applications of physics in astronomy before Saha entered this field.

In 1609, Gallileo heralded a new age in astronomy through the application of the telescope. A telescope is like a large sized eye. The

200" Telescope of Mount Palomar observatory can collect light of an area of about 31000 square inch in contrast to the very small size of pupil of the human eye of about a quarter inch. Consequently a telescope can intensify the brightness of star about 10^5 times of that detected by eye.

In 1666 Newton dispersed the spectrum of sunlight through a prism into violet, indigo, blue, green, yellow, orange and red colours, each containing a range of wavelengths, comprising a continuous spectrum. In a lens of telescope, diverged light is focussed at a large distance. But due to dispersion, rings of colours formed in the lens obstructs the view of the stars. Newton introduced a parabolic mirror instead of a lens, so that light of all wave lengths was reflected without any dispersion forming ring of colours as occured in a lens.

In 1957, John Dollond introduced the refracting telescopes with two different kinds of glass, one of which conceals the dispersing effect of the other. The largest refracting telescope based on his principle was installed in Yerkes observatory, Wisconsin, in 1897.

Still larger refracting telescope would absorb a large amount of light, so that it would cancel the advantage of its superior power of magnification. Evidently, large telescopes, today, are mostly of reflecting type, because the surface of a mirror absorbs very little light.

In 1814, Fraunhoffer, passing the sunlight through a narrow slit and refracting it by a prism could get a series of images of the narrow slit in light of all possible wavelengths. The images were so densely packed together that they formed a continuous spectra. Strangely, there were dark lines in this continuity. It is evidently due to some slit image missing from the spectrum. That is, light of a

particular wavelength is being absorbed in the solar atmosphere and cannot reach the earth. Fraunhoffer detected more than 700 such dark lines named after him. In 1842, Alexander Edmond Becquerel in France introduced the photography of the solar spectrum. With the help of modern technology, more than 30,000 dark Fraunhoffer lines are photographed till now with their wavelengths measured accurately. Soon it was evidenced that the wavelengths of sunlight are characteristics of various elements in the sun. It was the notion of the scientists that the dark lines are due to the absorption of a particular wavelength, emitted in the interior of the sun and passing through its relatively cooler atmosphere. But we had to wait to know its physical significance till the model of the atoms was worked out by Bohr.

Around 1850, Bunsen and Kirchoff made laboratory experiments to identify the line spectra of elements heating them to incandescence. They found bright lines of emission on a dark background element used in the experiment. It was also observed that a bright emission line passing through a cooler gas cell gets absorbed if the gas has an element possessing that characteristic line of emission and that will result in a dark line at the site of the wavelength of spectrum concerned. Bunsen and Kirchoff soon discovered two new elements caesium and rubidium with their spectroscope which had been used till then for studying the known elements.

In 1862, Angstrom detected the presence of hydrogen in the sun by the characteristic spectral line of the element, as observed in the laboratory by Bunsen and Kirchoff.

In 1868 Jansen, a French astronomer while observing a total solar eclipse in India, reported a new spectral line in the sun which could not be found in the spectra of any known element in the laboratory. Lockyer named the new element as 'Helium' from the

greek word for the 'Sun'. Thirty years later helium, a rare gas, was discovered on earth.

Hydrogen could also be found in the spectra of stars. However, the steller spectra showed variation among themselves due to the differences in their chemical constitution and other properties, some of which were still unknown at that time. Sechi classified the stars in around mid-nineteenth century according to the nature of their spectra. In 1890, Pickering and Cannon could collect thousands pattern, known as Harvard classification. Saha wrote his paper 'On the Harvard classification of Stars' in the light of his theory. As mentioned earlier also Saha revised the said paper on the advice of Fowler, who communicated it to the Proceeding of the Royal Society of London, entitled as 'On a Physical Theory of Steller spectra'. In this revised version of the paper, Saha acknowledged his indebtedness to Fowler for his keen interest in the work and his help in providing him with many valuable items of information, advice and critical comments in writing the paper.

In the Harvard classification in its final form, stars of decreasing temperature are arranged in order of stars with the letters O,B,A,F,G,K,M,R,N and S. Each class is subdivided by numbers 1 to 10. As an example, our sun has a medium surface temperature about 5500 degree centigrade belonging to the spectral class G5, while hotter stars like Procyon is F-5 (6500^0C) and Sirius (11000^0C) is A-O.

In 1885, Balmer observed a series of lines in the hydrogen spectra in the laboratory, which was regularly spaced obeying a rather simple formula. The physical significance of the Balmer series could only be explained by the quantum model of the atomic structure proposed by Bohr in 1913. He pictured the hydrogen atom consisting of a positively charged nucleus around which an electron circles it in any one of a number of orbits, fixed in position. When the

electron is excited from an inner to an outer orbit, it does so by absorbing a quantum of energy, of fixed wavelength, characterising one of the Balmer lines of absorption. The emission line represents a similar quantum jump, when the electron loses energy being dropped from an outer to an inner orbit. Very soon, Bohr model was successfully applied to the spectra of various elements. Balmer lines account for the spectra of hydrogen in the visible range, whereas Lyman observed a similar series in the ultraviolet range of the hydrogen spectrum. If a quartz prism is used instead of glass, which easily absorbs ultraviolet rays, the ultra violet part of the solar spectrum can pass through and be detected through a chemical reaction. In such a reaction, ultraviolet rays break the silver nitrate to silver, darkening the plate more rapidly than by an exposure to blue or violet light.

In 1860, Maxwell forwarded his famous electromagnetic theory predicting the radiation as electromagnetic. Ordinary visible light was a small portion of the whole electromagnetic spectrum. In 1887, Hertz discovered the radio waves and produced them by experiment. Those were in the longer range of wavelength than that of infrared beyond the visible red spectrum. Gradually the X-rays, Gamma rays of smaller wavelength or higher frequency than that of U.V. Ray, had been discovered extending the electromagnetic spectrum of radiation.

Very soon it could be realised in the 1890's that spectral analysis gives immense information about elements and that the steller spectra produced the finer details of the elements present in the stars.

Lockyer had demonstrated that the spectral lines of given element are altered at high temperatures. He observed differences in the arc and the spark spectrum of an element, representing the lower and the higher temperature respectively. The physical significance

of his works could only be appreciated on the basis of Saha's thermal ionisation theory. Before the due recognition of his contribution, Sir Lockyer died and at a later period Lady Lockyer gratefully acknowledged her indebtedness to Saha for his contributions, leading to the recognition of the past works of her husband.

Because of the World War I, it was not possible to receive the scientific information from abroad. After the World War, D.M. Bose, the Ghosh Professor of the physics department of the Calcutta University, interned in Germany, could return to India and brought with him some scientific papers including those on Bohr's contributions. Saha went through these papers, which inspired him to work out his theory. He was aware of the fact that due to high temperature in the sun, molecules are not only dissociated to atoms, but atoms are also split into ions and electrons.

A large amount of data on the steller spectra of neutral and ionised atoms was collected in different laboratories at that time. But it was a mystery that there were large differences in the intensity of line spectra in different stars. The Balmer lines of red part were observed to be feeble in the solar spectrum inspite of the large content of hydrogen in sun, whereas the Fraunhoffer line of calcium in the violet region was intense. Why is it so? In all the steller spectra, such discrepancy was prominent. Balmer lines in A class hot stars are prominent but gradually become less intense in the cooler stars. But in some hotter stars the intensity increases. There had been various suggestions to explain such anomalies but all without success.

Before Saha appeared on the scene, astronomers were divided into two main groups. One group led by E.W. Maunder argued that the chemical constitution of a star is the source of the variation in the spectra, such as the star with intense hydrogen lines in its spectra must have high hydrogen content and with intense helium lines would

be a helium star. Contrary to this conjecture, Miss Clerk of the other group at Harvard, had stated that the evolutionary stage of a star is responsible for the varied spectral intensity of the different stars. There were no conclusive proofs of both the concepts. The logic behind them was so incomplete that W.S. Adams had to remark 'we could hardly hope to understand the behaviour of matter in the distant stars, when the mechanism of light given out by a candle flame was quite unknown to us'.

Saha's theory based on his knowledge of thermodynamics and Bohr's quantum theoretical model of atoms could solve the problem to a large extent.

It was a common belief of the scientific community of Europe that Saha made his contribution under the guidance of Fowler in the Imperial College at London. Such belief was exposed in 1972 by A.J. Meadows in the biography of Sir Norman Lockyer, where he writes on the origin of the paper of Saha 'On a Physical Theory of Steller Spectra' as follows:

"Shortly after Lockyer's death, an Indian Physicist M.N. Saha came to work under Fowler at Imperial College. The paper he wrote during this visit, 'On a Physical Theory of Steller spectra' showed how the spectra of stars could be understood in terms of the new quantum theory of the atom together with the dissociation hypothesis. After some initial opposition, his results were rapidly accepted. The theory showed that both temperature and pressure affected the dissociation of atoms in steller atmospheres. So both Lockyer and his opponents are partly right. It is only fair to Lockyer to add that the influence of temperature on steller spectra is much more marked than of pressure.

Other aspect of Lockyer's work as on the structure of the solar atmosphere, or on the classification of the steller spectra were

superseded and forgotten almost by the time of his death. Saha had originally intended to call his paper 'On the Harvard classification of stars'. Fowler had to point out to him that some of the pioneering research in this area had been carried out at South Kensington".

Long before the above publication, in a letter to Plaskett, around December 1946, Saha clarified his stand against such wrong notions of the British scientists in another context. The relevant portions of the letter, the full text of which was published in *Mahaviswa Vol.* 4, 1983, may be quoted here:

"The occasion for writing this letter was a feeling, which I experienced during my two tours in Britain, that there has been a persistent effort on the part of British scientists to minimise (or rather should I say with a faint praise) my early contributions to astrophysics. This is borne out by your remarks in the 'Observatory', April 1946, where you say, 'Saha, working in Fowler's laboratory after, the end of the last war then demonstrated that the successive appearances of these different spectra could be interpreted as being due to the temperature and pressure, prevailing in the steller atmosphere. His work had in turn been put on a firm theoretical basis by R.J. Fowler and Milne, working at Cambridge and using the magnificent material accumulated by Lockyer, and so successfully interpreted by Baxandall'.

I regret to tell you that this remark is entirely gratuitious and misleading. It gives one the impression that I derived all the fundamental ideas in astrophysics which goes under my name, viz., the theory of Thermal Ionisation and its applications, from Prof. A. Fowler, while I was working as a scholar under him in 1920. This is entirely misleading, for I worked at Fowler's laboratory as a guest, and never registered my name as a scholar and the work had been mainly done in India before I went to Fowler's laboratory. For the information of yourself and other scientists who are of this

opinion, I may trouble you a little about my biographical sketch".

Here Saha gives an account of his teaching and research experiences, which was summarised earlier. He mentioned in this letter the reason why the larger paper on the Selective Radiation Pressure could never be published in the Astrophysical journal. He also mentioned that he might claim to be the originator of the theory of Selective Radiation Pressure, though on account of the above discouraging circumstances, he could not pursue the idea and develop it.

Saha further writes "E.A. Milne apparently read a note of mine in *Nature*, 107, 488 (1921) because in his first paper on astrophysical determination of average of an excited calcium atom, he mentioned my contribution in a footnote, though nobody appears to have noticed it. His exact words are: 'These paragraphs develop ideas originally put forward by Saha".

In the later part of the long letter, Saha comments on his association with Fowler as to the origin of his paper 'On a physical theory of Steller Spectra', as follows:

"I took about four months in rewriting this paper, and all the time I had the advantage of Prof. Fowler's criticism, and access to his unrivalled stock of knowledge of spectroscopy and astrophysics. Though the main ideas and working of the paper remained unchanged, the substance matter was greatly improved on account of Fowler's kindness in placing at my disposal fresh data, and offering criticism wherever I went a little astray out of mere enthusiasm".

The paper was read at a meeting of the Royal Society, and there Prof. Fowler spoke very enthusiastically about the work. He said that it was the greatest contribution in astrophysics since Kirchoff's discovery of spectrum analysis in 1859, and predicted a great

number of works being stimulated by it.

Fowler treated me as a colleague and a guest, never as a student. I have very great respect for him as a scholar, as a man, as an astrophysician, and for the unselfish and generous way he treated me, which I now find is rather unique, and I am quite sure that were he living now, he would have been the first man to resent your suggestion".

Saha did not want any doctorate degree of a British university, rather he was interested in verifying his thermal ionisation theory by experiment. He had no personal acquaintance with Albert Fowler except that he had read his paper on the spectrum of ionised helium. He narrates his first interaction with Fowler in the said letter to Plaskett, as follows:

"On my arrival in England, I saw Prof. Albert Fowler, who at first thought that I had come to work for the D.Sc. degree of the London University like other Indian students working under him, but when I explained to him that I wanted to work there only for a short period to obtain verification of my theory, he did not show himself very enthusiastic, but allowed me to read and work in his laboratory.

In the meantime, my first paper 'Ionisation in the Solar Chromosphere' communicated from India, had appeared in the *Phil. Mag.,* thanks to a personal call which I made on Mr Francis, publisher of the Journal. After its publication, Prof. Fowler began to take more lively interest in my work and in my views".

However, Saha, on the advice of Fowler went to Sir J.J. Thompson at the Cavendish laboratory to find out whether it would be possible for him to carry out tests on the experimental verification of the theory of thermal ionisation by observations on heated Cs and Rb. vapour. After a long discussion with Thompson, his

opinion was that there is no harm in trying the experiment as proposed by Saha. But it was found that the apparatus and materials in the Cavendish laboratory were insufficient for carrying out the work.

Then Saha had written to Eggert, to get Nernst's permission for him to work in his laboratory to pursue his proposed experiment. Receiving an encouraging reply from Eggert and Nernst, Saha reached Berlin in February 1921. There he carried out certain experiments on the electrical conductivity of heated caesium vapour with the results, which Saha thought to have established the truth of the ionisation theory. But Nernst raised several objections. Saha left the manuscript of a paper on the experiment and its results with Nernst before he left Berlin for India in November 1921.

He had to return to India at the request of the Vice-Chancellor of the Calcutta University, Sir Asutosh Mukherjee, who wanted him to join the newly created post of the Khaira Professor in the Physics department of the Calcutta University.

In India Saha did not hear anything from Nernst about his paper. So, he published it in the Journal of the Department of Science of the Calcutta University.

It was known after a while, that Nernst had suggested the solution of the problem from observations on the surface ionisation phenomena. E. Meyer, in Nernst's laboratory and I. Langmuir carried the experiment with success. Saha's publication in the local journal remained unnoticed. Had it been published in *Phil. Mag.*, Saha would have got due credit for his experimental work done in the laboratory of Nernst.

After joining as the Khaira Professor in the physics department of Calcutta University, Saha faced a very difficult situation. The post was created out of an endowment of Guruprasanna Ghosh of Khaira.

Sir Asutosh being the arbitrator in compromising a dispute between Guruprasanna and his wife Bageshri Devi, persuaded them to make a substantial gift out of which the posts of Khaira Professor of Physics and Bageshri Professor of fine arts were instituted. Abanindra Nath Tagore was appointed the first Bageshri professor. Saha, when appointed as the Khaira Professor in Physics, had a fixed salary of Rs. 500 per month and a house allowance. Compared to the Palit Professorship, it had no graded scale and had a much lower salary.

Secondly, serious differences of opinion emerged between Saha and Raman, the then Palit Professor and head of the Physics department. Earlier, Raman, when being talked of as the future Palit Professor, hinted to Saha to draw him within his orb to work under him. Saha declined, since Raman had no expertise in the line in which Saha was working.

Sir Asutosh now sided Raman in the matter of differences between Saha and Raman.

Thirdly, Saha could not get any laboratory space, research grant or any assistance. Ronaldsay, the then Governor and Chancellor of the Calcutta University was not supporting the programme of expansion of the post-graduate studies in the University as proposed by Sir Asutosh.

Earlier in 1918, both Saha and Bose were the applicants for a Readership in the Dacca University. On the recommendation of Prof. Jenkins, head of the Physics department there, S.N. Bose was appointed. Saha out of love to his Alma Mater did not try to migrate elsewhere.

Now, since the syndicate of the Calcutta University could not comply with his request for a research grant and a graded scale of pay, Saha had no other alternative but to try elsewhere.

Saha already declined the invitation to join the Kodaikanal Solar observatory as an Assistant Director under Evershed. Probably he did not like to serve a government organisation. He always preferred the freedom of a university where he could pursue his own line of research.

There were offers of Professorship from universities like Aligarh, Benaras and Allahabad. The offer of the Allahabad university appealed to him most, probably because his senior friends namely N.R. Dhar and A.C. Banerjee were already there. N.R. Dhar was trying his utmost to see Saha appointed in no time. Lastly Dhar wrote to Saha "Though a lobby is active against your appointment here, be sure that you are joining us very soon."

In 1923 Saha joined as Professor and Head of the Physics Department of the Allahabad University.

In 1938 Saha left Allahabad when he saw no hope of further improvement there due to increasing political interferences. He grew to dislike more and more the manner in which the university affairs were being managed.

Saha eventually relinquished his post at Allahabad, when Dr Shyamaprasad Mukherjee offered him the post of Palit Professor of Physics at Calcutta University, which lay vacant after D.M. Bose left it. Meanwhile, at this juncture an account of his scientific contributions would be appropriate to mention which brought him international fame in the world of science.

Saha himself narrated to Prof Plaskett in his letter mentioned earlier about how he entered the field of astrophysics without any help or guidance from any expert in the field. The first part of the said letter is as follows:

"It was while pondering over the problems of astrophysics, and teaching thermodynamics and spectroscopy to the M.Sc. classes that the theory of thermal ionisation took a definite shape in my mind in 1919. I was a regular reader of German journals, which had just started coming after four years of first World War, and in course of these studies, I came across a paper by Eggert in the *Physikalische Zeitzchrift*, 1919, *Uber den Dissociation Zustard der Fixterngase* (p 573) in which he applied Nernst's Heat Theorem to explain the high ionisation in stars due to high temperature, postulated by Eddington in course of his studies on steller structures.

Eggert, who was a pupil of Nernst and was at the time his assistant, had given formula for thermal ionisation, but it is rather strange that he missed the significance of ionisation potential of atoms, the importance of which was apparent from the theoretical work of Bohr, and practical work of Franck and Hertz, which was attracting a good deal of attention in those days. Eggert grasped the importance of 'Chemical Constant' for electron gas; It was natural enough for the idea of chemical constant was due to Nernst himself though it was given an accurate value by Sackur and Tetrode on the quantum basis. Eggert used Sackur's formula of the chemical constant for calculating that of the electron, but in trying to account for multiple ionisation of the iron atom in the interior of stars on these basis he used very artificial values of ionisation potential. Later, when I met him he told me that he had not realised the importance of Bohr's theory, or of Franck and Hertz's experiments, and had absolutely no idea that the ionisation potential can be calculated from spectroscopic data, as I had done. Further, he appears to have had no idea of problems of Solar Chromosphere or Physical characteristics of steller spectra, as was apparent to one like me who had read Miss Agnes Clerke's book. His knowledge of the problem of the steller

interiors was derived from a talk given by Kohlochütter in the Berlin Physicale Colloquium on Eddington's Theories.

While reading Eggert's paper I saw at once the importance of introducing the value of 'Ionisation Potential' in the formula of Eggert, for calculating accurately the ionisation potential, single or multiple, of any particular element under any combination of temperature and pressure.

I, thus arrived at the formula which now goes by my name. Owing to my previous acquaintance with chromospheric and steller problems, I could at once see its applications. I prepared in course of eight months of 1919 (February to September) four papers and communicated them for publication in the *Philosophical Magazine* from India within August to September."

The titles of the said papers have been mentioned earlier and how one of them was later changed at Prof. Fowler's suggestion and was published in the *Proc. Roy. Soc* (A) Vol. 99.

Saha's theory of thermal ionisation is expressed by the equation:

$$\text{Log } (x^2/1\text{-}x^3)P = U/2/3\ RT + 2.5 \text{ Log } T—6.5$$

Where x is the fraction of the ionised atom, P is the total pressure, U is the heat of ionisation, R is the universal gas constant and T is the temperature in Kelvin.

From the relation of U with the ionisation potential of Bohr's theory, Saha deduced the values of ionisation potential in electron volt and converted it to calorie. For Calcium, the value of U is 14090 calorie from its ionisation potential 6.12 electron volt.

In the same method he could calculate the accurate values of the ionisation potentials of Barium, Strontium, Hydrogen, Helium

etc. under various temperature and pressure.

In his paper 'On Ionisation in the solar chromosphere' Saha could prove that the chromosphere is mainly constituted of Calcium, Barium, Strontium, Scandium, Titanium and Iron ions. Beneath that layer both the ions and neutrals of the same element would exist. How the ionisation efficiency of an element depends on the pressure is well understood from the existence of the mostly ionised elements in the chromosphere. Because of the low pressure there, more ionisation occurs.

In the solar atmosphere, all the molecular hydrogen are dissociated to atoms. An important conclusion of Saha's theory is that the ionisation efficiency of elements of higher ionisation potential, will be less at the same temperature. Hydrogen and Helium are best examples of it. Their ionisation potentials are so high that those can not be ionised in solar atmosphere. Helium can be ionised in a star with surface temperature 16000^0K.

That the neutral Rubidium and Caesium lines are not present in the chromosphere due to their total ionisation because of their low ionisation potential, was proved to be true in the light of Saha's theory. Saha predicted their presence in the colder region of sunspots. From the photographs of the sunspots taken in the Mount Wilson observatory, before the publication of Saha's theory Rubidium lines were detected. The non-existene of Caesium line might be due to their complete ionisation even at the sunspot temperature.

In the paper on the 'Elements in the Sun' Saha could unequivocally explain the Fraunhoffer lines and the spectrum of the chromosphere of the Sun. He proved here that the sun consists of all the elements existing on earth. He showed that the presence of an element in the sun changes with the temprature and pressure and they respond to these conditions differently due to the difference in their structures.

Earlier there was no idea about the influence of pressure in stars. But Saha could show that the spectra in different layers of chromosphere change due to the difference in pressure in those layers.

In the paper 'On a Physical Theory of Steller Spectra', Saha applied his theory of thermal ionisation to the problems of steller spectra. He showed here that there is no need of marking a star as a hydrogen, helium or carbon star. In the steller structure, none of them can be said to be a main constituent of the star. In fact. the temperature and pressure of the star excite or ionise the atoms of the elements present. The spectrum of an ion differs in character from its neutral species. Russell used to give importance to the spectral classification ordered with the temperature. The physical significance of such classification is now understood from Saha's theory.

Harvard astronomers observed the difference in the width and the brightness of the spectra in some giant and supergiant stars. In those stars with high brightness, pressure is low. Russell thought that the difference in brightness is due to the difference of the density of gas on the surface. Since Saha's theory predicts the difference in ionisation efficiency through the influence of pressure, the idea can be applied to explain the variation in brightness in giant stars where ionisation differs due to pressure difference.

Saha's thermal ionisation equation was applied to many problems on the solar and stellar spectra. One example is the strong H and K lines named by Fraunhoffer due to highly charged ions of calcium. The unusual intensity of those lines normally suggests the abundance of calcium to be very low in the sun. Saha's equation suggests that the pressure and temperature prevailing in the solar chromosphere are sufficient to completely ionise the lowly abundant calcium atom in the singly ionised state because of its inherent atomic structure, resulting in very low ionisation potential. These ions form

a heavily absorbing layer producing strong spectral lines of wavelengths 3933 and 3968 angstroms. (1 angstroms=10^{-8}cm).

It has been mentioned before that Saha's theory could explain the changes observed in the spectral lines of stars due to more and more ions produced with increasing temperature in different stars, where the composition of elements need not be assumed to change. This confirms the temperature dependence of Harvard classification of the spectral sequences of stars.

The above mentioned papers added a new dimension in astrophysics.

Eddington, in his article on stars contributed to the *Encyclopedia Britannica* (4th edition) mentioned Saha's theory as an important land mark in astronomy since the first variable star (Mira Ceti) was discovered by Fabricus in 1596.

During his sojourn in Europe, Saha had a three weeks' trip to England as a delegate from the Calcutta University to Empire Universities conference held at Oxford in 1921. During this trip he visited Cambridge and also met Eddington who showed immense interest in Saha's works. Here he met Milne, a colleague of Eddington, who told him that he along with R.H. Fowler was working on the improvements on his theory of thermal ionisation, trying to apply it to more complex astrophysical problems.

Russell gave due importance to Saha's theory and its applications to the extensive field of astronomy.

De Vorkin and Kenat in the *Journal of History of Astronomy* (1938) write how Russell expressed his innovation to Saha's work in a letter to Adams. "I believe that within a few years, we may utilize knowledge of ionisation potentials and so, to obtain numerical determination of stellar temperature from spectroscopic data".

The same authors also present the text of a letter from Russell to Saha which states, "When I was appointed as a research Associate of this observatory, I planned at once to do what I could carry on work on the lines you have suggested. You will see that your predictions about the lines in the alkali metals in the sunspot spectrum have been completely verified. Rubidium is present. We will investigate caesium as soon as proper photographs of the spot spectrum near 8500 can be obtained".

From the above reactions, it may appear that the experimental verification of the theory contemplated by Saha seems to be unnecessary. But there were some contradictions from different laboratories showing results adverse to the theory. He wanted to verify the results in a laboratory experiment. His attempts in this regard are already mentioned.

In fact a few British scientists, in order to undermine Saha's work, claimed that Albert Folwer was behind Saha's contributions. The articles of Meadow and Plaskett are the examples of these claims. That induced Saha to write to Plaskett stating the background of his contributions in details, pleading against such wrong notions. The letter remained unknown to us till 1983. One can notice that persons like R.H. Fowler and E.A. Milne working on the premises founded by Saha were elected Fellows of Royal Society, London before Saha. Thanks to Albert Fowler, Eddington and Chapman who strongly promoted Saha's election to the same Fellowship in 1927.

Fowler proposed Saha for the said Fellowship in 1925 and Gilbert T. Walker, Ex-Director General of Observatories in the Indian State Meteorological Service, seconded the proposal. Election of Saha as F.R.S. was delayed by two years due to an adverse report of the Head of the Intelligence Bureau from India on his connection with revolutionaries. Even attempts were made to convince

Fowler and Walker to withdraw their proposals to which they did not agree. However, these adversities did not stand in the way of his election at last. So it is not surprising that Saha was not considered for the Nobel Prize in Physics, though a personality like Compton recommended him for the same.

Of course Saha gratefully acknowledged his indebtedness to. Fowler and Lockyer's earlier works with due regard for them.

In his contribution entitled 'Dissociation Equilibrium' in *Life and Works of Sir Norman Lockyer*, published in 1928, Saha paid his tribute to the Late Sir Lockyer, whose works could be duly recognised in the light of Saha's thermal ionisation theory.

A specific account of Saha's scientific contribution mentioned above is given by S. Rosseland in the Introduction to his famous book *Theoretical Astrophysics,* Oxford, 1936. An excerpt:

"Although Bohr must thus be considered the pioneer in the field, it was the Indian physicist Meghnad Saha, who (1920) first attempted to develop a consistent theory of the spectral sequence of the stars from the point of view of atomic theory. Saha's work is, in fact, the theoretical formulation of Lockyer's view along modern lines, and from that time the idea that the spectral sequence indicates a progressive transmutation of the elements, has been definitely abandoned. From that time dates the hope that a thorough analysis of steller spectra will afford complete information about the state of the steller atmospheres, not only as regards their chemical composition but also as regards the temperature and various deviation from a state of thermal equilibrium, the density distribution of various elements, the value of gravity in the atmosphere and its state of motion. The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has

Jagannath Saha, father of Meghnad Saha

Bhubaneswari Devi, mother of Meghnad Saha

Radharani Saha, wife of Meghnad Saha

Meghnad Saha and Radharani Saha with their children Ranjit, Ajit and Usha

On Carnegi Trust Fellowship in U.S.A., 1936

Saha (9) in the Copenhagen Conference in 1936. Also seen in the picture are Homi J. Bhaba (12), Neils Bohr (11), Lee Meitner (5) and Max Born (4)

Felicitating Pandit Jawaharlal Nehru after his release from prison in 1945 in the Science College Campus. Also seen in the picture is Dr. B.C. Ray

Saha (sitting second from right) with Harlow Shapley (sitting fourth from right) at a meeting of the Indian Science News Association in 1936

At the opening ceremony of Glass, Ceramic and Research Institute at Calcutta in 1950. Also seen in the picture are Dr. B.C. Ray, S.S. Bhatnagar, Pandit Jawaharlal Nehru and Dr. Atmaram

With President Rajendra Prasad

Saha in erstwhile U.S.S.R. with the Soviet space scientist
Dr. Anna Masevitch and Prof. Kapitza

been influenced by it and much of the subsequent work has the character of the refinements of Saha's ideas".

J.C. Bhattacharya has recently reviewed the refinements of Saha's theory done by different authors till now.

Russell in 1925 modified Saha's equation taking into account a mixture of elements instead of ionisation of one element considered by Saha. Depending upon the results of a laboratory experiment that the electron pressure in a volume of Calcium vapour changes appreciably, when other elements of low ionisation potentials are injected into it, Russell showed that the ion to neutral ratio of two elements was a fixed value dependent only upon pressure, relative abundance or the presence of other elements in the mixture (*Astrophys.* 1922).

Although Barium and Sodium have nearly the same ionisation potentials, more ionisation of Barium in the solar spectra could hardly be explained by Saha's theory. Russell and Saunders (*Astrophys.* 1925) studied alkaline earth spectra in detail with an answer for the above anomaly occuring due to the peculiar electronic structure of Barium.

Fowler and Milne (1923) refined the original Saha equation taking into account the statistical distribution of atoms in the excited states along with ionised states, instead of statistical interpretation of entropy in the original approach of Saha. They further modified the equation with the terms accounting for the number of valency electrons in lieu of total pressure in the Saha equation. Saha devised his steller temperature scale using marginal appearances of lines as points in the spectral sequence instead. Fowler and Milne used the maxima of a specific Fraunhoffer line as the temperature calibration point, since the former is affected by relative abundance.

Fowler and Milne applied the modified equation to various

lines of solar spectrum and found a new temperature scale consistent at least for the stars of spectral class later than AO.

Menzel derived a modified Saha equation using the number of atoms in unit volume of the neutral and ionised states in place of the fraction 'x' in the original equation and the partition functions of neutral and ionised atoms. His modified equation has been accepted widely in steller spectroscopy.

Cecilia Payne (1925) took help of the modified equation of Saha to compute shapes of intensity vs. temperature curves and devised an improved steller temperature scale. She proved that the Harvard classification essentially signified the degree of thermal ionisation, an idea voiced by Saha in 1920.

When the temperature is known from the steller temperature scale of Cecilia Payne, the relative abundance of atoms or ions of star may be estimated from the relative intensities of lines due to different atoms or ions particularly around the transition points. Earlier, the spectral temperature scale devised by Saha was based on the marginal appearances or disappearances of lines in the spectral sequence and was found to be affected by relative abundances and maximum intensity of Fraunhoffer line had to be adopted. But Saha's criterion for the temperature scale, later on, returned with a new possibility for determining the relative abundances of elements in a star as was first pointed out by Fowler and Milne after establishment of the steller temperature scale by Cecilia Payne.

In the concluding remark of his paper 'On Electron Chemistry and its application to Radiation and Astrophysics', Saha mentioned that at a higher temperature of the core of stars, some sort of reactions of atoms might be the steller energy source. Though nuclear reactions were not in his view, discovery of the thermonuclear fusion occuring at the high temperature of the core of a star, as the source of its

energy, was a logical sequence of Saha's concept of thermodynamic equilibrium picture. But Saha himself may not have imagined that his theory would be relevant to the phenomena of the Early Universe at extremely high temperature, as is emphasised by J.V. Narlikar in a review 'Saha Equation and Beyond' where it is shown that the Saha Equation has wider applicability to astrophysics and cosmology. He illustrated two scenarios namely the origin of the microwave background radiation in the recombination epoch of the universe and the origin of light nuclei in the early universe where Saha Equation can be applied.

In case of the origin of the microwave background radiation, the Saha Equation is modified with the fraction of ionised atom x as the ratio of the number densities of electrons and total baryon number density. Then for hydrogen atoms, the equation can be solved for x as a function of T. The results show a sharp drop in the value of x. For example, x=0.003 at T=3000 K for the case where the baryon density at present is ~ 2 x 10^{-30} g/cm^{-3}.

Evidently, at this stage most of the free electrons responsible for the scattering of photons are removed from the scene and the universe becoming effectively transparent to radiation, enters the recombination epoch.

Thus the Saha equation fixes the recombination epoch when radiation decoupled from matter. The microwave background seen today carries the signature of that epoch intact, enabling us to probe the early universe.

If we go further back in time to the 1—1200 second epoch, the universe was hot enough (T >> 10 -^{10}K) for primordial nucleosynthesis to have taken place. George Gamow in the late 1940s calculated how free protons and neutrons could combine to form bigger nuclei up to ^{4}He at this stage. The result is a reincarnation of the Saha equation with nuclear binding and its application to the

origin of the light nucleus shows a fairly good agreement with the observational estimates of the light nuclei supporting the big bang origin of the early hot universe as well as the thermodynamic equilibrium picture conceived by Meghnad Saha.

In the concluding remarks, the author observes "Work of a fundamental nature in physics inevitably finds unexpected applications.The Saha equation is an example".

In the laboratory of H.W. Nernst, Saha caried out certain experiments on the electrical conductivity of heated caesium vapour, the results of which were satisfactory to establish the truth of his ionisation theory. As mentioned earlier the manuscript of the above work left with Nernst, remained unpublished. However, an account of the work was published in the departmental journal. Saha proved the ionisation of gases by heat in that experiment. With this experiment, Saha was pioneer in introducing 'Laboratory Astrophysics' now a popular concept to simulate Astrophysical phenomena in experiments in a laboratory with modest facilities without the help of an Observatory or a big machine.

Under the guidance of Nernst, Meyer very soon experimentally proved the ionisation of caesium vapour in contact with hot tungsten filaments and almost simultaneously Langmuir and Kingdon (*Proc. Roy. Soc. Lond.*, 1925) arrived at a similar result.

The Saha equation modified with the electron density on the surface of the electron emitter, determined by Richardson law, could explain the above phenomena and the equation is now known as Saha-Langmuir equation.

In 1919 Eggert calculated the equilibrium constant for reaction of the type $x \rightleftharpoons x^+ + e$ with the absolute entropies of the atom x, ion x+ and the electron gas e. The modified equation based on the Saha's theory is now applied to quasi-neutral thermal plasma of atoms, ions

and electrons. The modified equation of Langmuir and Kingdon known as Saha-Langmuir equation opened a new field of research on surface ionisation of elements of low ionisation potentials. Surface ionisation ion sources devised on the principle of Saha-Langmuir equation constitute a major component of nuclear instruments like accelerators and mass spectrometers etc. Both the above equations have far reaching applications in plasma physics research, seeding a magneto hydrodynamic plasma by thermal ionisation.

In around 1970, it was observed that in the ionisation of Lanthanides at hot cavities, the ionisation efficiency is much higher than those predicted by the Saha-Langmuir equation. Kirchner and Piotrowski (*Nuclear Inst. and Math.* 1978) derived an ionisation efficiency formula for ionisation in hot cavities to be identical to the Saha equation. Such a system is explained by a thermal plasma generated by an ensemble of the flow of thermoionic electrons and surface ionised ions from the cavity walls into the volume ionisation included in the ensemble in thermal equilibrium.

While the surface ionisation depends on the elemental material, cavity ionisation depends on the different vapour pressures of the cavity materials.

In a cavity, the method of calculating the ionisation efficiency in a plasma of several elements with different partial pressures is to solve the Saha equation for the specific case.

It was observed that for the ionisation of trace quantity in a cavity with an element of ionisation potential <8 electron volt, the modified Saha equation is valid for temperature >2700 K in a Rhenium ioniser or for temperature >3000 K in a Tungsten ioniser, provided the orifice of the cavity is sufficiently small.

Kirchner (*Nucl. Inst. and Math.* 1981) has shown that 25

elements of ionisation potential <6.3 electron volt give high ionisation efficiency in surface ionisation, whereas 34 additional elements with ionisation potentials <8.1 electron volt are efficiently ionised in a hot cavity.

Thus, besides the astrophysical problems, Saha's thermal ionisation theory, in one form or the other, has opended an extensive field of research in Laboratory plasma and ion physics. Both these fields are of use in the development of plasma machines and ion sources for accelerators, isotope separators etc.

Saha found a deep contrast between the research atmospheres of Calcutta and Allahabad when he joined the Allahabad University as a Professor. Its physics department consisted of nearly 120 graduate and 20 post-graduate students. However, its skeletal staff contained of only one lecturer, one part-time lecturer and a demonstrator, none of whom could think of any research problem besides their teaching duties. The laboratory was not well equipped. Grants for research, laboratory equipments and even for books were so inadequate that after spending first few years in Allahabad, Saha felt like Robinson Crusoe stranded in a lonely island. When Saha asked for grants for purchase of important journals and latest books, the treasurer of the university pointing his finger to the existing book shelves asked Saha to finish reading all the books first and then to ask for fresh ones. His requests for grants to improve the laboratory used to be unheeded with similar remarks.

Things changed a lot after 1927, when Saha was elected Fellow of the Royal Society of London. Sir William Morris, the then Governor of U.P., a scholar and classfellow of Lord Rutherford congratulated Saha on the distinction in an informal letter. Saha took this opportunity to acquaint himself with the Governor, thanking him for his good wishes. He apprised him of the condition of his laboratory and requested him to help in conducting research work in

a better way.

The Governor complied with his request and sanctioned a research grant of Rs. 5,000 per year as personal recognition. In those days, the amount was not less, if not adequate.

The research atmosphere in the department gradually improved with the influence of Saha. With his research co-workers like N.K. Sur, P.K. Kichlu and K. Majumdar he had to work on research problems during the summer vacation, when there was no teaching load. But during that time of the year the temperature used to go up to 119 degree Fahrenheit transforming the city into a 'Jehannam' (i.e. hell), a word coined for Allahabad, two hundred years before by a British traveller Fanny Parkes.

The dedicated efforts of the team raised the research contributions of the Allahabad University to a cognisable state in a few years. Young researchers of promise were gradually joining Saha from different parts of India.

A review of work conducted by Saha at Allahabad shows that the researches on both the theory and experiment were conducted in a balanced manner.

Much of the work here on classification of spectra, in spite of handicaps due to want of proper apparatus, was of considerable importance. However, during 1923-1938 Saha set up a spectroscopic laboratory at Allahabad now known to be one of the best equipped laboratories in India.

There were difficulties of publication for papers communicated to a foreign journal. It used to take not less than a year for them to be published. Because of these difficulties, sometime one had to be deprived of the credit by losing the priority of publication. Papers published in India would remain unnoticed by the scientific commu-

nity of the world and could be ignored.

Saha discovered the origin of complex spectra but lost the priority of the work since Hund forestalled him by a few months.

He formulated new ideas on formation of active nitrogen in the atmosphere on the basis of collision of the second kind, which stimulated a large amount of work by other authors.

In December 1937, Eddington on a trip to India to attend the Silver Jubilee Session of the Indian Science Congress, visited Allahabad on an invitation from Saha. Citizens of the city gave him a civic reception on this occasion. Eddington, in reply to the felicitation given to him, congratulated them and raised the question why an observatory for astronomical researches could not be founded in India, when a personality like Saha was there.

The answer to it was evidently the enormous dearth of financial resources required for this purpose in the British regime. Saha could well understand the reason. So, he gave up working on steller problems and instead turned to the ionospheric researches, which was then a subject close to astrophysics. Saha's ionospheric researches focussed on the problems of theory of the origin of the different layers of ionosphere and theory of propagation of the vertical radio waves through the ionosphere.

The origin of different layers of ionosphere is allied to the theory of thermal ionisation. Saha's theory of thermal ionisation is valid for a system of thermodynamic equilibrium, but there are systems which are in the state of thermodynamic non-equilibrium. Earth's atmosphere is an example of such a system. In 1922, Saha had already drawn attention to the problem and Milne solved it. He applied his solutions to the astrophysical problems, since this is also true for stars to some extent.

Pannekock applied Milne's results to the origin of E and F layers of ionosphere, discovered by Appleton in 1925. Saha published a series of papers in Indian journals on this problem and elucidated it further. A full account was published in *Proc. Roy. Soc. Lond.,* 1937 by Saha in the Paper entitled 'On the action of Ultra violet sunlight upon the upper atmosphere'. Saha and his co-workers showed in these papers that (i) oxygen molecules are completely dissociated by the action of sunlight at the height of 100 km or so and (ii) the origin of different layers of the ionosphere are probably due to the monochromatic ultraviolet emission of sun, though it is possible for the continuous spectra to produce them provided their intensity is million times larger assuming the sun as the black body i.e. in thermodynamic equilibrium.

Saha's remarks in the above paper are worth mentioning here: 'The discussion also shows that the ultraviolet radiation from the sun differs widely from that of a black body, and in selected wave lengths, the sun must be emitting nearly million times more photons than is given by a black body at 6500 degrees. This may possibly be due to the fact that the ultraviolet spectrum of the sun may consist of a continuous background of faint light on which are superposed emission lines of H. He, He+, Fe+ and other elements which are represented in the visible range by lines of subordinate series, or by patches of ultraviolet continuous light (near about 7500) leaking through the solar atmosphere from a much hotter region inside the photosphere, as suggested by Prof. H.N. Russell.'

In 1936, Saha elaborated the above problem in a note in the Bulletin of Harvard College Observatory with a suggestion of photographing the ultraviolet spectrum of the sun at a height over the ozone layer on the stratosphere.

This suggestion on the one hand indicates Saha's foresight on the importance of high altitude space research and on the other, the

problem on the ionisation in the ionosphere by solar ultraviolet rays, which do not reach the earth through the ozone layer.

To the gratification of Saha, after about sixteen years of the above suggestions, a group of physicists of the Colorado University photographed the solar spectrum at a height of 80 km by the V2 rockets developed by Germans during the second world war. The results of the experiment agreed with the predictions of Saha that emission of Lyman line ä1216 of hydrogen is prominent and there is no continuous background present. Further experiments yielded results quite in agreement with Saha's conceptions. Today space vehicles are common tools for such experiments.

The Ionospheric school of Research at Allahabad developed experimental skills in ionosphere research. In 1934 a new type of reflection of radio waves from ionosphere was discovered at Allahabad by G.R. Toshniwal corresponding to Appleton's third condition. This gives $fx_2=f^0-0.65$ megacycle instead of $fx_1=f^0+0.65$ megacycle where f^0 is the frequency of the incident and fx_1, fx_2, are those of the reflected radio waves. The results later on were verified in the university of Oslo by Leiv Harang.

The discovery of a fourth condition of reflection given by $fx_3=f^0+0.14$ megacycle was due to two students of Saha namely B.D. Pant and R.R. Bajpai. This new condition appeared to be puzzling at the time. Appleton had assumed that radio waves propagated vertically were reflected from the ionosphere, when the refractive index which decreases with electron concentration becomes zero. To Saha it appeared that the waves are reflected, when the group velocity of electrons becomes zero not only for the three conditions of reflection given by Appleton, but also under a fourth condition explaining the observation of the same by Pant and Bajpai.

Even after leaving Allahabad Saha had been pursuing research

with his pupils viz. B.K. Banerjee, U.C. Guha and R.N. Rai, on problems of the vertical propagation of radio waves and deduced the complete wave equations of the same, the solutions of which appear to be still remote.

At Calcutta, Saha conducted ionospheric researches with the help of B.M. Banerjee and R.N. Roy who developed an ionospheric recorder with nearly ten times more resolving power than the existing ones. Appleton paid a spontaneous tribute to the work, and suggested using it to prove or disprove the reality of lunar tides in the ionosphere.

With this apparatus R.N. Roy and J.K. Das Verma for the first time separated the direct echoes reflected by the ionosphere from those scattered by passing electron clouds. The polarisation ellipses of the resolved echoes reflected from the ionosphere.

In 1952, Saha resigned from the Palit Professorship of the Calcutta University and was appointed the Director of the Indian Association for Cultivation of Science and an Honorary Director of the Institute of Nuclear Physics founded by him. Meanwhile he left pursuing the ionospheric research in his institute in favour of S.K. Mitra, who took over as the Head of the newly started division of Radio Physics and Electronics and wished to develop a fullfledged ionospheric laboratory in his department. Saha had cordial relation with Mitra as his collegue and was responsible for persuading the Asiatic Society of Bengal to publish the renowned book *The Upper Atmosphere* written by S.K. Mitra. Saha wholeheartedly supported the programme of ionospheric researches of Mitra and did not like to develop a parallel line in the same campus.

At Allahabad, Saha was eager to start an experiment again to test his ionisation theory and associated inference from it. He had to wait till 1929, when Royal Society of London awarded a special

grant of £ 1500 for purchase of the apparatus. In the past, trying his utmost even through an influential personality like Tej Bahadur Sapru, Saha could not succeed in securing any grant from the Government of India for this purpose.

Thus the apparatus was set up and its details were published in the *Treatise on Heat* which he wrote with B.N. Srivastava for the use of advanced research students (1935). Saha's students B.N. Srivastava and A.N. Tandon were associated with this work. After Saha left Allahabad, Srivastava continued to work with it. With this apparatus he could not only prove the theory of thermal ionisation, but could also verify a few deductions from the theory and could determine the electron affinity of halogens.

It is reported that even today the apparatus is in operating condition and is being used for Ph. D. work of the Allahabad University.

In 1936, Saha extensively toured Europe and the U.S.A. on a Fellowship of the Carnegi Trust of the British Empire.

In Munich he realised the impact of developments in Nuclear Physics. He spent a month in Oxford and then proceeded to the Harvard College laboratory at Cambridge. In U.S.A. Saha visited E.O. Lawrence and his cyclotron laboratory. In this trip, he attended the International Conference on Nuclear Physics at Copenhagen, where world renowned nuclear scientists of that time had assembled. He could know there the possibility of nuclear fission which can produce enormous nuclear power in future. He exchanged his ideas with a number of scientists there. The subject of nuclear science impressed him so much there that he turned to its development in India. Thus his idea took a concrete shape in founding the Institute of Nuclear Physics out of the Palit Laboratory set up by him in the Physics Department of the Calcutta University.

It may be mentioned that Saha took a serious note of the puzzling results of Fermi on the possibility of uranium fission by neutron discussed in the same conference. Meitner very soon undertook the experiment ultimately leading to the discovery of Atomic Fission by Hahn and Strassman two years later.

Saha started researches in cosmic rays as the Palit professor of Physics at the Calcutta University in 1938. He conducted researches on determination of the life time of mu mesons from the simultaneous measurement of cosmic ray intensity at Calcutta and Darjeeling. Automatic Wilson cloud chambers were set up for the cosmic ray research. However, Saha had to discontinue these works for paucity of funds.

Saha devised a nuclear chart in which all known isotopes are plotted in A-I diagram, where A=Mass number, I=A-Z the isotope number and Z=atomic number expressing the excess number of neutrons over number of protons. The chart enables one to find the rules of $\delta\zeta$ stability at a glance. Prediction can be made from the chart on the stability of nucleus yet to be discovered. This sort of chart has now been widely extended by the nuclear physicists to predict the positions of neutron-deficient and proton-rich shortlived nuclei and to study their properties with radioactive isotope separators on line with an accelerator or a nuclear reactor.

Saha with his students derived expressions for the energy release of positron emitters over a wide range of mass of nuclei, obtained from the Bethe-Weizsacker formula.

Under his guidance S.K. Biswas and A.P. Patro obtained experimentally the fission cross section of U-235 for slow neutrons. Due to the world war and the secrecy maintained by U.S.A. the results of such experiments conducted there were not known to the outside world. When after the world war the data were declassified

and released, it was verified to be in good agreement with experimental results obtained at Calcutta.

Modern high vacuum equipments including Geiger counters needed for the nuclear instrumentation were developed in the laboratory of Saha with the help of the small workshop of the University.

In spite of his preoccupation with teaching and research in nuclear physics, Saha in 1945, had investigated the origin of the 'He' lines in the solar chromosphere, where neutral helium lines are strong but are absent from its Fraunhoffer spectrum. But the line of helium ion ä 4686 angstrom is found in the lower layers only pertaining to an excitation potential of 75.25 electron volt. But it is not expected for the chromosphere to have a temperature for excitation over 9 to 14 electron volts. Saha suggested in this work that high velocity alpha particles generated in the sun through nuclear process move outwards and are slowed down through ionisation. When they are sufficiently slowed down, they begin to capture electrons in different orbits 1s, 2p etc. When the electron is captured in any orbit higher than 1s, we have an excited helium atom, which will emit a characteristic spectral line and revert back to a lower state. Most of the lines are in the far ultraviolet region and the only line available for observation is ä 4686 angstrom. The capture takes place in any one of the 4f, 4d or 4p, 4s orbits and the above line is emitted when the electron jumps back to any one of the 3d, p, s orbits.

Hence it was necessary to know the cross section of such transitions to verify the above suggestion.

In view of this Saha with D. Basu calculated in 1945, the probability that an alpha particle passing through hydrogen gas would capture an electron in its 2p orbit from the ground state of

hydrogen atom, which constitutes about 90 percent of the solar atmosphere.

The capture problem also plays an important role in explaining the spectrum of aurora borealis, formed due to injection of charged particles from the Sun into the earth's atmosphere.

The method of the calculation of the above cross section was an extended version of that followed by Brinkman and Kramers, who came to the conclusion that the capture probability in the higher orbits is negligible compared to that in the 1s orbit. Results obtained by Saha and Basu were contrary to the conclusions of Brinkman and Kramers.

Apart from the application of the electron capture problem applied by Saha to the solar chromosphere, the problem has now a very wide field of applications in the energy range of electron volts to million electron volts. In this context, the above work of Saha is referred to as a pioneering contribution in the physics of Atomic collisions.

At Calcutta his major activities centered around the installation of a 38" Cyclotron capable of accelerating protons to 4 MeV. It was entrusted to Dr. B.D. Nag Chowdhury and a batch of workers under him. Though Saha entered into Big science in India through the cyclotron project, its success had been rendered difficult due to the lack of infrastructure in the country at that time. Technical knowledge was in a poor state, funds were meagre and after all, during the world war some components imported from U.S.A. with the help of Alfred Lumis of the laboratory of Lawrence at Berkely, could not reach India due to a shipwreck caused by an enemy attack. Saha did not live to see the successful application of the cyclotron in the nuclear physics researches, because of his untimely death.

In 1946 in a paper published in *Nature*, the origin of radio

waves from the sun and stars, Saha predicted the emission of 21 cm wave from steller bodies due to change of spin of nuclei of hydrogen and local magnetic fields. Van der Hulst had, however, forestalled the prediction of Saha one year earlier, a fact not known to Saha because of difficulties in communication, due to war. Hulst proved that such waves are emitted due to atomic collisions in space and a hydrogen atom can emit such a wave once in eleven million years. Of course, the space is spread with so much hydrogen that such rare events frequently happen. In 1951, Purcell and Ewen in Harvard University, Pawsey and others in Australia, and some workers in Holland were able to measure the wave length of the predicted emission and gradually it helped in charting the spiral arms of our Galaxy. That our Galaxy rotates once in 200 million years was detected through the doppler shift of the 21 cm waves emitted by it. In short, emission of the 21 cm wave has opened up a new window for looking into the steller world and it is accepted as a fundamental contribution in physics.

Saha directed one of his students to further explore the properties of the 21 cm waves. Unfortunately the said student joined Government service, since Saha could not provide him with a job. Such handicaps due to the migration of his students were faced by Saha from time to time, because of the paucity of funds.

Earlier in 1936 Saha, while investigating the origin of neutrons and protons calculated in a simple way the strength of a magnetic monopole to be $e/20\alpha$, where e is the charge of electron and α is Sommerfeld's fine structure constant. The value was in agreement with that predicted by Dirac. In his theory Dirac had also predicted its existence with a mass of about 10^{-8} gramme and an equivalent energy about 10^{-16} giga electron volt following the law of mass energy equivalence of Einstein.

Some cosmologists think that at a temperature of the early

universe, when the grand unification of nuclear and electro-weak force was inherent, magnetic monopoles might have played a role. However, free magnetic monopoles still remain undetected and the predicted properties have not been verified.

Saha had also carried researches on the determination of age of minerals by uranium-lead method with Dr. B.D. Nagchowdhury, which could not be pursued further because of non-availability of instruments like a mass spectrometer. However, he approved the programme to develop a mass spectroscopy and isotope separator laboratory in his institute initially by setting up a mass spectrometer with an inhomogeneous magnet of the Siegbahn-Svartholm type used in β spectroscopy. Saha of course did not live to see the success of his vision.

It may seem remarkable that Saha had the talent to carry on researches on Nuclear physics and the Particle physics of Dirac simultaneously with other frontier work in Astrophysics. He would have undoubtedly gone much ahead in these fields had he received timely support in manpower and equipment.

A few scientific contributions of Saha have been outlined here and it is not possible to go into further details in a short space. Readers interested in more details, may refer to the *Collected Scientific Papers of Meghnad Saha* published by the Council of Scientific and Industrial Research, New Delhi (1969) and the *Meghnad Saha Birth Centenary Commemoration Volume* published by the Saha Institute of Nuclear Physics (1993).

In spite of his preoccupations with research, Saha was a sincere teacher. He never limited his lecture notes to the available text books and scientific journals often with considerable hardship. His advanced text book *Treatise on Heat* and the junior text book on 'Heat' were the outcome of such compilations. He wrote *Treatise on*

Modern Physics with N.K. Saha. All the above books were published when he was at Allahabad. Sometimes he utilised his verbal discussions with students in the class or the seminar lectures assigned to the students, to pick up some of them for his research programme. He had followed Edison, who said that success in research is only two percent inspiration and ninety eight percent perspiration. This quality is not present in all students who show a good record in examination. Spoonfeeding was not his principle to guide a student in research.

In 1938, when Prof. A.V. Hill, the then Secretary of the Royal Society of London, visited his laboratory at Calcutta, Saha introduced his research students, about thirty in number to him. Hill wondered how Saha could guide so many students at a time. Saha modestly said that most of them did not require any guidance. Saha only had to provide them with monetary grants and facilities.

Saha did not hesitate to permit his students to work independently if they wanted to do so. At Allahabad, R.C. Majumdar and D.S. Kothari were the two students whom he supported for conducting their research outside the area of his interest.

When Kothari after returning from the U.K. was looking for a suitable job, Saha took help of the then Chief Justice of Allahabad High Court, Sir Shah Mohammed Suleman, who was his good friend. On Sir Suleman's recommendation Kothari was appointed Reader in Delhi University. In such a situation, Saha had always extended his helping hand to his students. Even, those students, who would not have an aptitude for research or further studies, had been placed in other suitable service on recommendations by Saha.

Saha had a progressive mind in formulating the syllabus of a course. In 1940 he introduced the general and special nuclear physics courses for the post-graduate degree in physics of the Calcutta

University which was a pioneering effort in India. He organised a laboratory for the practical works of the students in the special nuclear physics course and also set up experiments on determining the cosmic ray intensity, on measuring β-energy by thin window Geiger counters and energies of alpha particles by a Wilson cloud chamber. The above experiments were fabricated with the indigenous materials available in the country. Only the radioactive source would have to be imported from abroad.

On Saha's recommendation, H.J. Bhabha who returned from Cambridge in the 1930s, was appointed by the Calcutta University as the paper-setter and examiner of the said special course examination held for the first time in 1942. By that time, Saha had recognised the immense potential of Bhabha, which was subsequently realized in the building up of the Nuclear India by Bhabha.

Till 1953, Saha himself had to teach the special nuclear physics in post-graduate classes. No texts on the subjects were available in India at that time. Saha had to spend considerable efforts in preparing his lecture notes from the latest available journals.

He personally conducted the researches in Nuclear Magnetic Resonance, β Spectrometry during fifties at Calcutta. Experiments with the NMR spectrometer and the thin lens β spectrometer, fabricated indigenously in his laboratory were the pioneering ones in India. In all these activities Saha conducted discussion courses with the students involved in these projects.

Either in classes or in popular lectures, the orations of Saha used to be so exciting and inspiring that it was always an unforgettable experience for the listeners.

Saha won accolades both within the country and outside for his renowned scientific contributions. But he had his detractors too both

in the country and abroad. However, they did not succeed in the long run. Saha handpicked research students and trained them with great care. Those of his students who had been in the services other than research fondly recalled Saha as the preceptor for the whole life. All of his students had maintained lifelong student-teacher relationship with Saha. Thus Saha's influence was felt all over India in almost all spheres of profession, be it scientific research, administration or else.

This popularity and influence endeared him to large section of the Bengali intelligentsia, but earned the hostility of many. His scientific outlook forced him to take an uncompromising stand against any move denigrating the importance of science in the country.

IV

THE ORGANISER AND THE BUILDER

Saha joined Calcutta University as Palit Professor in 1938. After Raman left the same post in 1932, D.M. Bose was appointed Palit Professor for a short period. He had to leave it to take over as the Director of the Bose Institute founded by J.C. Bose, who was his maternal uncle.

As Palit Professor, Saha concentrated his activities on organising the studies and researches in nuclear physics. In 1941 when a majority of the scientists world over were unaware of the potential of nuclear energy, Saha could explain the discovery of Hahn and Meitner in a lucid language. In an article in *Science and Culture* (Vol. 6) he elucidated the importance of nuclear energy for future, when fossil fuel sources would be depleted. Evidently his foremost activity started with the installation of the 4 MeV cyclotron in Palit Laboratory.

Jawaharlal Nehru had been patronising science long before we achieved independence. In 1940 Saha was appointed a member of the Board of Scientific and Industrial Research of the Government of India, which later on became a part of the Council of Scientific and Industrial Research (CSIR). Saha was then known to Nehru as a renowned scientist of the country. Saha requested Nehru to exert his influence in securing a financial grant from the Tata Trust for his cyclotron project.

Some people had wrong notions that Saha had no concrete ideas about the large financial involvement in the installation of a big machine like a cyclotron. Others thought that Saha born of a middle

class family, had little experience of handling a large amount of money. But Saha was fully aware of the responsibility of the cyclotron project. Saha knew that our country lacked technological infrastructures, which were easily available in the developed countries. He was against the thinking of our countrymen that no such big science could ever be introduced in such a situation. As a member of the National Planning Committee formed in 1938 he had thought that some industries would gradually develop to be able to support scientific researches.

It is true that Saha was not brought up in an affluent family but his ideas were not limited because of this background. Rather, he had nurtured the dreams of large investments by the Government in industrialising the country. In his time, cyclotrons had been installed in many small universities of the developed countries. So a 38" diameter cyclotron was not an unrealisable dream for a pioneering university like Calcutta, which was then the biggest in India.

However, financial grants from the Tata Trust and the Krishnarpan Charity Trust Fund were available for cyclotron through Nehru's influence. But Calcutta University had declined to accept the grants, on the grounds that the grants were not sufficient and the university would have to shoulder the full responsibility of the project, which was beyond its means.

Nehru had to intervene at that stage. B.C. Roy and S.P. Mukerjee at his request convinced the senate of Calcutta University and the senate accepted the above grants.

In 1945 Saha initiated an electron microscope laboratory for Biophysics research with the help of N.N. Dasgupta. Saha could receive donations from Birla, R.P. Saha and B.C. Laha for this purpose and organised Biophysics department in the University.

In 1947, Saha attended the Rutherford Conference on Nuclear

Energy held in Paris. In this conference, Saha was inspired by the nuclear research activities of the European Laboratories. On return to India, he was determined to set up an institute for nuclear science research.

The aim and the object of the proposed institute was to train the students in nuclear science and to pursue and promote researches in the same. Meanwhile, the biophysics laboratory had been organised under the leadership of N.N. Das Gupta. Ajit Saha led the group working on the theory and experiments on beta gamma spectroscopy and B. Purkayastha in nuclear chemistry. In the Science College campus on a small piece of land, donated by the Calcutta University, Institute of Nuclear Physics was setup. Its foundation stone was laid by Dr Shyama Prasad Mukherjee, the then Civil Supply Minister of the Government of India. Madam Curie-Joliot formally inaugurated the Institute on January 11, 1950. The ceremony was held in the presence of Lady and Sir Robert Robinson, J.D. Bernal and many leading scientists of the country. K.N. Katju, the then Governor of West Bengal presided over the inaugural function.

The Calcutta university senate approved the constitution of the said institute on an agreement between the Government of India, and the Calcutta university. When the constitution was approved by the Central Government, the institution was declared to be autonomous with a Governing body consisting of the Vice-Chancellor of Calcutta university as the ex-officio president, M.N. Saha, then the Palit Professor as the life member and honorary director of the institute, and representatives of the Government of India and Calcutta university as members.

Saha was pioneer in starting a post-M.Sc. course in nuclear science for imparting training to young scientists in India. The all India character of the institute was maintained by admitting a certain percentage of students into the course from outside West Bengal.

A student's hostel adjoining the institute was soon built on another piece of land donated by the university. K.D. Malviya, the then minister of the Government of India laid the foundation stone of the hostel on January 19, 1956.

By that time the institute had been developing on the following lines of research:

(a) Particle Accelerator with a cyclotron.

(b) Nuclear Physics with alpha, beta and gamma spectros copy, nuclear induction techniques and microwave spec troscopy.

(c) Instrumentation with electronics.

(d) Nuclear chemistry.

(e) Theoretical nuclear science.

(f) Neutron physics.

(g) Post-M.Sc. teaching.

(h) Biophysics.

At that time the accelerator division had a cyclotron, and a neutron spectrometer. It was designing a Cockroft Walton Generator for producing neutrons through deutoron-triton reaction and a mass spectrometer on the principles similar to double focussing beta ray spectrometer for mass analysis of high masses and for separation of small amounts of isotopes at low masses.

The nuclear physics division had undertaken studies on beta gamma spectroscopy, nuclear induction and paramagnetic resonances with microwaves. Nuclear chemistry and theoretical nuclear science division had not yet been developed to the extent as desired.

Saha died on February 16, 1956 before all the above mentioned activities took a proper shape but the institute became renowned later for producing scientists of international repute and for fruitful researches thus realising the objectives for which the institute had been founded. In 1958, the institute was named as the Saha Institute of Nuclear Physics.

In 1969, the West Bengal Government donated seven acres of land in Bidhannagar for shifting the institute from the Science college campus. The buildings at Bidhannagar were constructed with the financial grants from the Department of Atomic Energy under a tripartite agreement of the Department of Atomic Energy, the West Bengal Government and the Calcutta university. By 1990, the institute was shifted to Bidhannagar. In 1992, the earlier constitution of the institute had been modified with the Chairman of the Department of Atomic Energy, Government of India, as the Chairman of the Governing Council of the Saha Institute. The building of the institute along with the cyclotron at the Science college campus was donated to the Calcutta university. The Calcutta university has renamed the building and its auditorium as Meghnad Saha Bhaban and Meghnad Saha Hall respectively on the occasion of the Centenary Celebration of Professor Saha. Earlier the Biophysics division had been shifted to a site at Belgachia adjoining the Veterinary College building of the Government of West Bengal. At present the Saha Institute of Nuclear Physics at Bidhannagar has about ten divisions pursuing researches on nuclear physics with the Variable Energy Cyclotron which is installed by the department of Atomic Energy in Bidhannagar adjoining the Saha Institute and on plasma physics, nuclear theory, solid state physics, super-conductivity, atomic collision physics, nuclear chemistry, biophysics, molecular biology and a few other branches of Physical Sciences. For the accommodation of the staff of the institute, quarters have recently been built on a plot of land adjoining the institute donated by the Government of West Bengal.

Since 1938, Saha had Been interested in the activities of the Indian Association for the Cultivation of Science founded by Mahendralal Sarkar. From the laboratory of the Association at 210, Bowbazar Street, Raman could make his famous discovery for which he was awarded the Nobel Prize in physics in 1928.

Since 1913, Saha had been attending the seminars and lectures held in the Association. In 1926 he was enrolled as its life member. Till 1934 he had no role in administration of the Association. When Shyamaprasad led a group of member to oppose the modification of its constitution proposed by Raman, Saha took an active role in support of Shyamaprasad. In 1942 Saha was elected the secretary and later on the vice president of the Association. In 1946, on the death of U.N.Brahmachari, the president of the Association, Saha was elected president in his place.

Saha, as the president of the Association, organised its research activities with an extensive programme. Execution of the programme had evidently been vested upon him. Saha took the initiative to find a more spacious accommodation for its extended activities. Saha succeeded in securing financial grants from the Government of India for the building and the Association was shifted to its new site at Jadavpur after the construction was completed. The annual grant of the Association from the Government of India had also been enhanced. At Jadavpur, the covered area of the building was nearly 36,000 square feet. In 1950, Saha accepted the post of the fulltime Director of the Association and resigned from his post of Palit Professor of the Calcutta university.

In 1976, the contribution of Late Meghnad Saha in bringing the Association to the status of national importance was remembered with applause in the centenary celebrations of the Association, inaugurated by Mrs. Indira Gandhi, the then Prime Minister of India.

In 1925, Saha was elected sectional president in physics at the Indian Science Congress. He spoke on "Thermal Ionisation" and outlined the contemporary discoveries in physical sciences and astronomy. He stressed upon the want of encouragement and dearth of facilities for research work in India. He had stated "The researcher who wants more money for his work, is not infrequently treated like Oliver Twist in the Charity House. He has asked for more! Even in medieval and ancient times, it was considered a duty on the part of the state to help the seekers after truth".

Saha had struggled all his life and battled against Government apathy to get adequate grants for his researches. Even after independence, grants for university researches had been poorer than that for the national laboratories.

In 1927, Saha attended the International Conference of physicists held at Como, Italy, on the occasion of the death centenary of Volta. Later on he joined a total solar eclipse expedition to Ringeby at 68^0 N. Earlier, he had given a theory of the spectrum of chromosphere and now had a satisfaction to observe the flash of the chromosphere at the moment of totality.

During a meeting of the Indian Science Congress Association at Allahabad, a meeting of the scientists of U.P. was also held. In this meeting the then Governor Sir Malcolm Hailey (later Lord Hailey) advised the scientists to form an Academy of Science which would contain authoritative representation of all the specialised branches of scientific work in the province.

In accordance with the sentiments expressed by the Governor, a committee of U.P. scientists was formed with the object of forming an association. As member of the committee, Saha took a leading part in drafting the objectives, rules and regulations of the society modelled on the lines of the Asiatic Society of Bengal.

On March 1, 1932, the U.P. Academy of Science was inaugurated at Allahabad in a meeting presided over by the Governor. Saha was elected its first President and Sir Malcolm sanctioned, at Saha's request, an annual grant of four thousand rupees for the Academy.

Saha was elected the General President of the Indian Science Congress Association for the session held in Bombay in 1934. In his presidential address, he elucidated the importance of forming an All India Academy of Science as the supreme coordinating body of Indian scientists, empowered to act as a liaison body between other scientific societies. A committee was formed under the Chairmanship of Sir L.L. Fermor, Director of the Geological Survey of India and M.N. Saha and S.P. Agharkar as organising secretaries.

Saha's proposal to start an all India Academy met with controversies and ultimately two other academies namely Indian Academy of Science at Bangalore patronised by C.V. Raman and the U.P. Academy renamed as the National Academy of Science came into existence.

But Saha's proposals eventually led to the establishment of the National Institute of Science as proposed by him. On January 7, 1935, its formation was formally announced at a meeting held in the Senate Hall of Calcutta university under the Chairmanship of Dr. J.H. Hutton, President of the Indian Science Congress for the year. L.L. Fermor was elected the first president of the Institute. Saha was elected its president for the 1937-39 term. Saha took initiatives to transfer the headquarters of the National Institute to Delhi. Later, it was renamed as the Indian National Science Academy.

In 1933, Saha founded the Indian Physical Society at Calcutta which published the Indian Journal of Physics. At present the Journal is published by the Indian Association for the Cultivation of Science

and jointly edited by the Indian Physical Society. In earlier days, eminent scientists like Raman, Saha, Krishnan and others had regularly contributed their important papers to this journal.

In 1935, Saha founded the Indian Science News Association at Calcutta for dissemination of science amongst the public. The Association started publishing a journal called *Science and Culture,* where Saha had written a large number of articles on the various problems like River Valley Development, National Planning, Industrialisation, Education, Calendar Reforms and on popular science. Besides contributing to *Science and Culture,* he had written numerous articles on similar problems in other journals too.

The above articles are published in a few volumes as *Collected Works of Meghnad Saha* by the Saha Institute of Nuclear Physics.

Saha was a member of the Council of the Indian Institute of Science, Bangalore for six years, when J.C. Ghosh was the Director of the Institute during 1938-1948. During that period, an all round extension and reorientation of the research activites of the Institute had been carried out. New departments like Metallurgy, Power technology and Aerodynamics were created; the department of Radio Communication Engineering was separated from that of Electrical Engineering. As a member of the Council, Saha had played a prominent role in these developments. It was due to his initiative and persistence, that the department of Power technology had come into existence.

Earlier, it was mentioned that Saha was appointed a member of the Board of Scientific and Industrial Research, constituted in 1941, at the initiative of Sir Ramaswamy Mudaliar, then the Indian member of the Viceroy's cabinet, to mobilise Indian scientists and industrialists in the task of developing the resources of the country. S.S. Bhatnagar appointed as the Director of Scientific and Industrial

Research (CSIR) had been in charge of the board. Two years later, the Council of Scientific and Industrial Research was established with the earlier constituted board as its part.

Saha had been a member of the Governing Body and other committees, since the inception of the said Council. He contributed substantially to its growth and activities in organising the National Laboratories under it. Saha and his colleagues wrote a large number of articles which laid the ground work for these developments. He had played a prominent role in the establishment of the Central Glass and Ceramic Research Institute at Calcutta. He had been a member of its planning committee and the Chairman of the advisory board for many years.

Bhatnagar was a good friend of Saha. But on occasions, when Saha disagreed with the policy and methods of CSIR, he did not spare Bhatnagar from criticism. Bhatnagar had admitted it in a letter of appreciation on Saha's sixtieth birth anniversary:

"Prof. Saha is a veteran nationalist. Some people consider him to possess a very critical faculty but his criticisms are usually actuated by a desire to get more help for scientists and scientific institutions in every field and not against personalities". Saha had a prominent role in the foundation of the departments of Radio Physics and Electronics and Applied Physics of the Calcutta university. In organising those departments, Saha closely associated with the developments and exerted his influence to secure financial grants for this purpose. Out of the department of Radio Physics and Electronics of the Calcutta university, a new department of Computer Science has grown up along with the Eastern Centre for Researches in Radio-Astro Physics as an agency of the Calcutta university, which was inaugurated in 1993 by Shri K.R. Narayanan, the Vice President of India.

In the matter of organisation of various concerns, Saha had to face interventions from civil servants of the Government. It was considered customary that only the civil servants were suitable for the posts of the secretaries in the ministries, though they lacked in technical know-how. Saha had the conviction that the above custom had been the cause of the inefficiency of the Government. At one time, Bhatnagar, though an eminent scientist and a Fellow of the Royal Society, London, was not allowed to contact the member in charge (corresponding to the rank of a Minister) directly, but only through the secretary, who had been either a man of civil service or finance service. Saha had criticised the system in a strong voice in *Science and Culture* which induced the Government to grant Bhatnagar the rank equivalent to that of secretary with the right of direct approach to the Minister. Since then, the appointment of men of science or technology in a similar responsible post in a ministry is not barred any more.

V

THE PLANNER AND THE REFORMER

SAHA had an inborn interest in the problems of rivers. He had witnessed the horror of flood every year in the area of his native village. In 1913, Saha, then a post graduate student served as a volunteer in teams organised by Krishna Kumar Mitra, a veteran leader of Brahmo Samaj for flood relief works at Tarakeswar and Uluberia area, when the Damodar river flooded the areas in the Burdwan Division in a catastrophic magnitude. His interest in the Damodar river emerged initially during that relief work.

In 1917, Lord Ronaldsay, the then Governor of Bengal, ordered an investigation of the causes of recurrence of flood in Damodar river in response to a mass petition headed by the Maharaja of Burdwan. The reports of the investigation submitted by the engineers like Glass, Suberwal and others were lying unheeded in the Government files, till 1943 when the next flood ravaged the area.

In 1923, floods in North Bengal caused extensive damage to communication and standing crops. The misery of people of the isolated villages was extreme and the Government would not move in relief works. Acharya P.C. Ray organised the North Bengal Relief committee and entrusted Subhas Chandra Bose, Meghnad Saha and Satish Chandra Dasgupta with the overall relief work in the area. Ray had been able to collect a large fund from the public for this purpose. The relief organisation was a great success under the supervision of Bose, Saha and Dasgupta. A large number of staff members including Saha left aside their research work for some time

to devote themselves to the relief works.

Saha, based on his experiences, soon wrote an article in *Modern Review* suggesting measures to control the flooding of rivers. This article was the beginning of his plans for river research in India. In the same year, Saha contributed an article "Need for a Hydraulic Laboratory in Bengal" in the Seventieth Birthday Commemoration Volume of P.C. Ray. In this article he proposed to establish a research laboratory for the studies of river control, flood, irrigation, navigation and hydraulic power development based on the model of similar laboratories abroad. He also proposed to undertake hydrographic survey of flood of Indian rivers including collection of data on topography, precipitation etc. to be useful in the construction of hydraulic project. His proposed plans were materialised after about eleven years when the Bengal Government established the Bengal River Research Institute at Haringhata.

In his presidential address to the Indian Science Congress held in Bombay, Saha stressed upon his plans on the hydraulic research laboratory. Saha did not limit his works to the Bengal rivers only. In 1938, in his presidential address to the National Institute of Science, he focussed the problems of Indian rivers particularly of the deltaic ones. Damodar River planning was his most outstanding and significant contribution in this direction. The next flood in 1943 isolated Calcutta from rest of India. Saha dealt with this issue elaborately.

Due to the forceful writings of Saha in the daily press and because of his public speeches, the then Bengal Government appointed a Damodar Valley Enquiry Committee in 1943 under the chairmanship of the Maharaja of Burdwan. Saha was a member of the Committee.

Saha represented the case of Damodar river in the meetings of

the Committee. He clearly showed how to handle the river system for multipurpose use taking the model of Tennesse river system under the Tennesse Valley Authority (TVA) in USA.

The article of Saha with Kamlesh Roy, published in *Science and Culture* in July, 1944 had been a landmark in the history of development of river system and showed how similar problems of other rivers of India could be solved.

In a number of articles, editorial comments in *Science and Culture* during 1943-44, Saha created public opinion and shaped the policy of the Government regarding river control based on modern engineering and technology.

Saha had made an extensive study on the TVA plans and programmes and pleaded that engineering transcends nationality and the model of TVA Engineering pattern could in principle be successfully adapted to the Damodar valley. Saha set up a model of the Damodar River in the corridor of his laboratory in the science college compus.

Dr B.R. Ambedkar was then the member-in-charge of power and works, in the Viceroy's cabinet. Saha had often discussed with him and his secretary D.L. Majumdar his plans regarding the Damodar river. At the instance of Dr Ambedkar, the Government adopted a resolution to set up a Damodar Valley Corporation after the model of the TVA and D.L. Majumdar was deputed to the Tennesse Valley to study its constitution. Majumdar drafted the Damodar Valley Act which was adopted by the Government of India. W.L. Voorduin, a Tennesse Valley expert, was appointed to draw up the plan for the Damodar Valley. On his report, published after a year and a half, Damodar Valley Corporation was set up in March, 1948.

Preliminary Memorandum on the Unified Development of

Damodar River was a forty page publication by the Central Technical Power Board containing 13 exhibits like different kinds of maps of the valley, records of rainfall, hydrographs and tables. It included a summary by H.M. Mathews, the chairman of the Board and criticism of some aspects of the plan by A.E. Green, chief engineer, PWD, Bihar, S.K. Guha and Mansingh of the Irrigation department, Bengal.

It was surprising that in this publication no acknowledgement was made to the articles of Saha published earlier, though the specific recommendations of the TVA experts closely agreed with those of Saha. Saha did not confine his plans to dams only. He considered the utilisation of the hydro-electric power and water resources optimised on the basis of a balanced development of the entire Valley.

Saha's interest was not confined only to Bengal rivers. On his persuasion, K.G. Bagchi of the department of Geography of the Calcutta university made a comprehensive study of the problems of the Mahanadi delta and his masterly survey of the subject published in an article, indicated ways of tackling them.

Sir Arthur Cotton discovered the Hirakud site more than a century ago. The Central Water Power and Inland Navigation Commission submitted a plan for construction of the Hirakud dam and its foundation stone was laid by the then Governor Sir Howthorne Lewis on March 15, 1946. After the transfer of power by the British Government, Jawaharlal Nehru, the first Prime Minister of India, laid the second foundation stone of the Hirakud dam in 1947.

Many renowned engineers, notably Sir M.C. Rugiya, who was responsible for the construction of the Krishnarjunsagar Dam in Mysore and once a member of the Orissa Flood Enquiry Committee in 1939, pointed out many defects of the scheme and Bagchi in an article in *Science and Culture* commented: "It is difficult to escape

the conclusion that the Government project (at Hirakud) has been drawn rather hastily."

The comments had been true for both the Damodar Valley and Hirakud along with the Bhakra Nangal Project in the Punjab, which had been the subject of investigation of the committee of the parliament and three Enquiry committees. In 1947 July, Saha, in an article published in the *Science and Culture* issued a warning to the Government with his following concluding remarks:

"The multipurpose development of rivers can be affected only through a definite procedure. The following are the steps in any scheme of development :

(1) Survey of the inherent character of the land and the natural resources — water, minerals, soil, vegetation.

(2) Planning on a multipurpose basis so that power, navigation, irrigation, land use and flood prevention are integrated in an efficient way.

(3) Design.

(4) Construction : Systematic researches should be constantly taken help of for a sound construction of the plan.

(5) Utilisation : An optimum utilisation can be assured only on the basis of a balanced development of the entire valley.

In spite of these warnings, blunder had been committed in the execution of the above three Development Schemes.

Saha had always stressed that only such persons should be appointed as the members of the Corporation who are of high integrity and intelligence, of wide experience of men and affairs with a clear conception of the economic development in India on modern scientific lines, specially in the industrial and agricultural fields.

Saha had suggested categorically what should be the structure of administration and method for execution of the plan regarding the above development schemes. But his suggestions were ignored during the development stages.

Today, whenever there is an occurrence of a natural calamity in the area of the dams, already constructed, Saha is sometimes blamed for the origin of the ideas on river planning, but the fact that no one heeded to his suggestions and his advice in these matters was mostly ignored.

Saha had great regard for the workers and leaders of the freedom movement. He had not joined any political movement once he decided to devote himself to science. But he had liberally extended monetary help to the political sufferers albeit in a secret way.

Saha had a great reverence for his teacher P.C. Ray, who had been a staunch supporter of the freedom movement. But Saha did not agree with Ray, who inspired his pupils to join the movement with the example of Italian chemist Cannizaro, who on the call of Garibaldi, closed his laboratory, shouldered a gun and joined Garibaldi's irregulars in his Sicilian campaign. Contrary to such advice, Saha had adhered to his science laboratory and to his teaching.

Saha again disagreed with Ray who had supported the Khaddar movement as a part of the freedom struggle. Saha had been strongly opposed to the slogans raised in support of such movement, such as 'go back to the village', or the cry for conventional cottage industries and khadi culture. Saha had a strong conviction that after independence, it would be impossible to fight poverty, disease and malnutrition without the use of modern science and technology, on a large scale.

Saha eleborated his views in an article "On the philosophy of

Industrialisation" published in the *Modern Review* (1938).

Whenever Saha came to Calcutta from Allahabad, he used to call on Acharya Ray to pay his respects to him, but the dispute between them on Khaddar did never resolve in spite of their long discussions on that particular issue.

In spite of his difference with Saha on the question of Khaddar, Acharya Ray entertained a great affection for him. When Saha was in Allahabad, Ray used to be a guest in his house from time to time. After Saha settled permanently at Calcutta, Ray used to spend days together at his house.

In 1935, Saha started publishing *Science and Culture*, the first copy of which was sent to eminent persons of the country. Netaji Subhas Chandra Bose, then at Karlsbad, for health reasons had received a copy and wrote in appreciation :

"The appearance of *Science and Culture* is to be warmly welcomed not only by those, who are interested in abstract sciences but also by those who are concerned with nation-building in practice. Whatever might have been the views of our older "Nation Builders" we younger folk approach the task of nation - building in a thoroughly scientific spirit and we desire to be armed with all the knowledge which modern science and culture can afford us. It is not possible however, for political workers with their unending preoccupations to glean that knowledge themselves, It is therefore, for scientists and scientific investigators to come to their rescue".

These comments by Bose were perfectly in tune with the objects of the Journal outlined by Saha.

In 1938, The National Academy of Sciences at Allahabad held a Symposium on "Power Supply" and Jawaharlal Nehru, then a prominent national leader was invited to preside over the occasion.

Opening the discussion, Saha compared the per capita output of work per year in India with the west, which was 20 times higher than the Indian output. Moreover, most of the output in the west was derived from electrical power whereas India's output was mostly manual.

Since 1935, Saha focussed this issue in the editorial articles of *Science and Culture*. In the Academy symposium, he urged for adequate planning to ensure cheap and abundant supply of power for the nation.

Nehru summarised the discussion with his comments that the Congress was not blind to the urgency of the matter. He suggested the Academy to draw up definite proposals which might benefit the nation. He assured that they could develop public opinion and put pressure on the Government to generate the much needed electric power.

Saha proposed a vote of thanks to Jawaharlal Nehru with these comments :

"It was in the fitness of things that Pandit Jawaharlal Nehru has agreed to preside over this annual general gathering of scientists in India. His position in the country can be described by a phrase which Americans use with respect to Abraham Lincoln : 'First in war, first in peace', and next to Mahatma Gandhi, he occupies the first place in the hearts of his three hundred and fifty million countrymen. The time has now come for him to give a lead in peace time work of reconstruction and consolidation of the country".

In the above comment, it is clear how Saha entertained great regard for the national leaders like Mahatma Gandhi and Pandit Nehru.

In response to Nehru's ideas, Academy drafted resolutions and transmitted it to the Congress headquarters. The resolutions con-

tained an eleborate plan for exploring natural resources of power, to do the needful in generation and distributing electrical power for the nation.

Very soon Saha's thoughts did not remain confined only to the power problem but were also extended to the national planning of the country.

The Indian Science News Association invited Netaji Subhas Chandra Bose, the then president of the Indian National Congress to preside over the third annual general meeting of the Association held on August 21, 1938, where Saha put the following questions to the Congress president, which revealed his own ideas in national planning for future India :

"May I enquire whether the India of future is going to revive the philosophy of village life, of bullock cart, thereby perpetuating servitude, or is she going to be a modern industrialised nation which, having developed all her natural resources will solve the problem of poverty, ignorance and defence and will take an honoured place in the comity of nations and begin a new cycle of civilisation?"

"If the Congress High Command decides on a policy of industrialisation, are they going to set up a rationalised scheme of industrialisation and establish a National Research Council and mobilise the scientific intellegentsia of the country?. I put the question because the Congress has come into power in several provinces and because there is a great confusion of ideas regarding the future industrialisation of India".

In reply to this question, Netaji expressed the feeling that for the task of national reconstruction, the aid of science would be first and foremost. He had also referred to his Presidential address at the Haripura Congress session where he had asserted that congressmen

had not only to strive for liberty but they had to devote a portion of their thoughts and energy to problems of national reconstruction with the aid of science and scientists of the country.

Netaji was wholeheartedly for large scale industrialisation and had said that what the nation had to face was not industrial recovery but industrialisation. He was in favour of an industrial revolution from which there was no escape.

He expressed, "We can at best determine whether this revolution, that is industrialisation, will be a comparatively gradual one, as in Great Britain, or a forced march as in Soviet Russia. I am afraid that it has to be forced march in this country."

Netaji announced there that they were moving in the direction of economic planning without waiting for the advent of Purna Swaraj by setting up a national planning commission very soon.

Netaji stated his own ideas in these words :

"Though I do not rule out cottage industries and though I hold that every attempt should be made to preserve and also revive cottage industries wherever possible, I maintain that economic planning for India should mean largely planning for the industrialisation of India. Industrialisation, as you will all agree, does not mean the promotion of industries for manufacturing umbrella handles and bell metal plates, as Sir John Anderson would have us believe".

Netaji, in conclusion, gratefully recognised the magazine *Science and Culture* for publishing thought provoking articles on industrialisation, electric power supply, flood control, river physics, the need for establishing a National Research Council etc.

Netaji, in his speech, had outlined his principles of national planning in the direction of modern industrialisation and indicated

the divergence of views in the Congress ranks. Nevertheless, Netaji was in favour of industrialisation for the following reasons :

i) For solving the problems of unemployment.

ii) For transferring a good portion of the population from land to industry.

iii) For socialism which presupposes industrialisation and the new generation which prefers socialism for the society.

iv) For improving the standard of living of the people at large.

Netaji concluded by assuring that the Congress party of India would play the role of promoting the national unity and solidarity, when foreign domination had ceased.

Evidently, Saha's thought on national planning were completely in unison with those of Netaji. Netaji had determined to set up a National Planning Committee, which was brought into existence shortly after his above interaction with Saha on this own initiative as the president of the Indian National Congress.

Saha had always held that political freedom without economic and technical freedom was meaningless. He had advocated these ideas on national planning in a number of articles and speeches. After his interaction with Netaji, Saha could convince him of the necessity of forming a National Planning Committee. The events leading to its formation were given by Saha in his article "Rethinking our Future" published as a pamphlet and later on published in *Science and Culture* (1953).

The National Planning Committee formed by Netaji at Delhi in October, 1938 had started working in Bombay the same year under the Chairmanship of Pandit Jawaharlal Nehru with Professor K.T. Shah as the hony. General Secretary. In the Delhi meeting earlier, Sir

M. Visweswaraiya was requested to be the Chairman. Saha dissuaded him from accepting the chairmanship on the grounds that unless a prominent congressman was made the Chairman, the decision of the Committee would be useless. Sir Visweswaraiya agreed with Saha. On Saha's suggestion, Nehru was invited to accept the chairmanship of the Committee.

Saha had been a member of the Main Committee, Chairman of Power and Fuels Sub-Committee and a member of the Sub Committee on River Training and Irrigation. His reports on the work of these Sub Committees bear marks of industry, knowledge and devotion.

In a final meeting of the main Committee held at Delhi on 26th March, 1939, it was decided to submit the interim report to the then Congress president Dr B. Pattabhi Sitaramayya, who by that time had replaced Netaji. The hasty decision to submit the report had been due to the premonition of a situation that the leaders would not be left free for long.

Twenty six volumes of the reports of the Sub Committees along with one volume of the report of the National Planning Committee were submitted by Pandit Nehru to the then president of the Indian National Congress with a request to draw up a scheme for the continuation of work of publication of reports and statistical data.

Shortly afterwards, Pandit Jawaharlal Nehru along with other leaders were imprisoned in the Ahmednagar Fort, where he wrote his famous book *Discovery of India*. In this book, his reflections on the national planning were eleborated. He had analysed how the National Planning Committee had to resolve the differences amongst its members, who represented the different sectors of the country. He expressed his ideas on planning in the following words :

"An industrially backward country will continually upset the world equilibrium and encourage the aggressive tendencies of the

more developed countries.

I am all for tractors and big machineries, and I am convinced that the rapid industrialisation of India is essential to relieve the pressure on land, to combat poverty and raise the standard of living, for defence and a variety of other purposes".

In fact, there had been a little difference in the ideas of Netaji, Saha and Nehru regarding national planning and it was expected that after independence the recommendation of the National Planning Committee would be repidly executed. But there was a strong divergence of view amongst the Congress ranks as to the above recommendations. Internal opposition within the Congress stood in the way, so that a Planning Advisory Board with nominal power could be formed. The years 1947 to 1950 were the years of "Economic Confusion" with an uncertainty in the policy of national planning. However, a Planning Commission was formed by the Government in 1950. The Commission submitted its interim report in 1952 and a full report and Industrial Programme in 1953. Sarat Chandra Bose, the elder brother of Netaji Subhas Chandra Bose was then a member of the first interim cabinet. He persuaded Saha to contest the Constituent Assembly elections. Saha decided to be within his regime of science and hence did not respond to the proposal.

After independence, Saha had apprehended that the management of river projects was improper and the planning was confused. His projects and criticisms through *Science and Culture* could no more be effective as before. His participation in the Congress government had been impossible due to his uncompromising attitude towards the Congress policies. The only alternative he could think of, was to voice his protests from the opposition bench in the Parliament.

Under the British Rule, Saha had been anti-establishment and frequently rebelled against the measures hampering education and scientific researches in the country. It was unfortunate that he had to play the same rolè after independence. Saha contested a seat in the Parliament from the Calcutta North-West constituency as an independent candidate and returned with a big majority. Though he was supported by the leftist parties, he joined none of them.

Saha had been unhappy with the reports of the Planning Commission and severely criticised them with constructive ideas. These were depicted in the pamphlet, entitled "Re-thinking our future", which was, later on published in *Science and Culture* in three parts in 1953 (March, April and June).

In this respect, he was clear in pointing out the deficiencies of the reports and had expressed the view that after independence per capita income had decreased beyond control. Due to blackmarketing and other reasons more money had accumulated with the rich and the poor had become poorer. A confusing situation had emerged in lieu of the classless society envisaged by the Congress.

Saha showed that through the plans of the Commission, per capita income would increase two times in 27 years. But it was doubtful, since only investment envisaged by the Government with out a correct economic planning might not succeed in fulfilling the target. In Saha's estimation, the planning of the Commission would not enable the country to improve the situation.

Saha had indicated that the plan fell far short of what was expected by the Prime Minister stated in *Discovery of India* as "we calculated that a really progressive standard of living would necessitate the increase of National wealth by 500 or 600%. That was however a big jump for us, and we aimed at 200 to 300% increase

within 10 years over".

Saha had expressed that Nehru's target was not superfluous in the sense that the USSR could increase its per capita income two times in 9 years. Laws of Economics are universal like those of gravitation. National planning had to be tied with these economic laws.

Saha had long association with P.C. Mahalanobis and had regard for him in the matter of economic planning. Saha had used the Mahalanobis formula and proved the futility of the plan worked out by the Commission.

Saha had suggested methods for successful planning as noted below :

(a) A National Economic Budget must be prepared.

(b) The rate of investment must be increased to 10 to 20% of the nation's income. The higher the better.

(c) The investment must be such as to yield large dividend.

(d) The population should be kept down by propaganda through birth control as far as practicable.

He had discussed the pros and cons of the national economic budget in the said pamphlet and proposed to set up a national economic service in the country. He had also stressed the need of setting up heavy industries like iron and steel, heavy chemicals, metals etc.

He had strongly criticised the Bombay Plan, where a number of Bombay industrialists connected with the Tata enterprises, produced a fifteen-year plan for India's development. Nehru had also found many lacunae in it.

About after five years of the criticism by Saha, Government established a few steel factories with foreign collaboration.

Gradually, the difference of opinions between Nehru and Saha grew deeper due to Saha's continued and strong criticism and opposition of the establishment.

In setting up the Atomic Energy Commission of India, the opinion of Saha was solicited. Saha disagreed with the proposal and advised the Government to build up the requisite infrastructure and to produce a large group of trained scientists before entering into such an enterprise. His advise was not followed and the Atomic Energy Commission was created in1948 under Homi J. Bhabha, as its Chairman.

D.M. Bose, senior to Saha, analysed the above event, in his Meghnad Saha Memorial Lecture (Proceedings of the National Institute of Science of India, 1967) in these words :

"The decision of the Prime Minister to locate the Department of Atomic Energy and Atomic Energy Commission with Bhabha as the secretary of the former and chairman of the latter must have caused some disappointment to Saha. Since 1935 Nehru and Saha had cooperated in many fields of common interest, including the formation of the planning committee of the Indian National Congress in 1938 by Subhas Chandra Bose with Nehru as chairman and Saha as an important member. A growing estrangement with the Prime Minister on some to his later decisions may have been one of the factors which decided Saha to enter politics in 1952. There can be no doubt, however, as the events shaped subsequently, that Prime Minister Nehru was undoubtedly right in entrusting Bhabha with the development of India's plan for utilisation of atomic energy. Bhabha identified himself completely with the development of atomic energy in India. Saha's interest were many and varied."

Indeed, Saha had varied interests. He had interest in atomic energy more than any other field. But from his experiences of facing difficulties with the cyclotron project, he felt the inadequacy of the infrastructure of the country in initiating a project on big science in India. It was not rare, that Nehru on a few occasions had accepted constructive suggestions of Saha. However, the advice of Saha was ignored by Nehru on the development of atomic energy in India. In the light of the present status of the atomic energy programme of India, it may be observed that Nehru had remarkable foresight in entrusting Bhabha with the development of atomic energy. Because of his hesitation, Saha had to be out of the venture.

Saha had been appointed a member of the University Commission by the Government in 1948 under the chairmanship of Dr Sarvapalli Radhakrishnan. The Commission had toured the whole country, visiting all the universities and other institutions of university rank and had interviewed the persons concerned. Meanwhile Saha focussed the problems of university education and its reforms in his articles and speeches. He played an important role in the activity of the Commission, which proposed the following recommendations:

(1) That university education should be placed on the concur rent list e.g. with autonomous administration,

(2) That the President of the Republic should be the visitor of all universities,

(3) That the concern of the Central Government with the universities be with regard to finance, coordination of facilities in special subjects etc.

(4) That for allocating grant to universities a central grants commission be established.

The above recommendations reflected the ideas of Saha in the reformation of university education.

In the parliament Saha advocated the issues on the need of provision of ample finances for universities by the Centre. He was unhappy with the inaction of the Government to effect the recommendations of the Commission.

In his speeches in the U.K. (*Nature,* 1945) Saha had cited the example of the USSR, which lost one crore forty lakhs of people in the second world war. But after the war, they courageously undertook the reconstruction of the universities. For Moscow University alone they spent about a hundred crores of rupees. Radhakrishnan, once told him, how thrilled he was by what he had seen there; wished he could have witnessed similar occasions more frequently in his own country. It appeared that universities being ill equipped, could not supply a constant influx of qualified votaries into the temple, built as national laboratories, to bring life into it.

Saha had been vocal in the parliament criticising the Government policy in river management, large scale industrialisation, university education, reorganisation of states and refugee problems.

At a later period, an autonomous University Grants Commission instituted by the Government fulfilled the vision of Saha, but its budgetary provision was not adequate as envisaged by him. However, the university education was later on, attached either to the Centre or states and not placed in the concurrent list, the results of which can now be assessed by the educationists of the country.

Saha opposed the Government policy for rehabilitation of the refugees from East Bengal in places outside Bengal. He had also been opposed to the proposal of Bengal Bihar merger in the parliament.

In the Lok Sabha debates, he had expressed his opinion against

the foreign capital of campanies predominating in the Indian market and opposed proposals of foreign collaboration sought by the Indian companies.

Saha's love of mathematics, absorbing interest in the Ancient Indian history and Astronomy led him to significant researches on the reform of Indian calendars. His contributions on the origin of the Saka Era had been classic in this field. Saha entered in the calendar reform work, when CSIR formed the Calendar Reform Committee in 1952 under his chairmanship.

The Committee examined about thirty different Indian calendars, which were full of confusion like the history of India. The Committee submitted its final report in 1955 with recommendations proposing the introduction of a scientific civic calendar for India.

Saha made major contributions towards compiling the report and analysing the scientific basis behind the proposals. Based on these recommendations the Positional Astronomy Centre of India publishes a National Almanac every year in collaboration with the International Astronomical Union, which is incorporated in some of the regional almanacs.

But still in some conventional almanacs discrepencies occur while fixing the dates of religious festivals determined by the lunar calendar. These conventional almanacs follow the national almanac in calculating eclipses etc, but for fixing the dates of religious festivals, they take the help of ancient observations of 570 A.D. Besides that the length of the year now differs by 23.8 minutes from the results of the ancient calculations. Due to the precession of equinoxes, sun now passes the equinox 23 days after the time ascertained in about 500 A.D.

The Calendar Reform Committee gave due considerations to these issues in preparing the almanac on a scientific basis with

modern astronomical observations.

It it unfortunate that some conservative almanac makers ignore the event of precession of the equinoxes and follow the ancient calculation which now needs to be modified on a scientific basis.

In the preface of the report of the Calendar Reform Committee, Nehru desired that there should be a certain uniformity in the calendar for civic, social and other purposes and that it should be done through a scientific approach to the problem. He hoped that scientists would extend their leadership in this field.

Saha led the Calendar Reform Committee in the right direction and through his significant contributions in the report established the social consequences of science in a broader field.

Saha had, all along his life, stood for science and technology and their social consequences. His entry into the parliament was motivated to steer the national policies for the upliftment of the society with a scientific outlook. All his activities were confined to his expertise on modern science.

In the parliament, he had to associate with some opposition leaders on the national issues like refugee rehabilitation and state reorganisation. Those issues made him popular, no doubt; but those gave him a stint of political exposure, too. He had to follow the rules of the game.

Saha was so much disturbed over these political issues, that he had to pass his last days in an agitated state of mind. His health was not keeping well in those days. Even so, he left for Delhi to meet J.C. Ghosh, then a member of the Planning Commission to hand him over some papers on the programmes of his institute.

On February, 16, 1956 Saha collapsed while walking in a steeet near Rashtrapati Bhavan in Delhi. He was rushed to the

hospital, where he was declared dead.

The Prime Minister Pandit Jawaharlal Nehru, Cabinet ministers, members of the parliament and others paid their last tributes to Saha in the hospital.

The untimely death of Saha at the age of 63, was the death of a martyr, who dedicated his life for spread of science and technology in India. In his death, India lost one of her worthy sons and the world, a distinguished scientist of the century.

Saha, once in his presidential address to the Physics and Mathematics section of the Indian Science Congress quoted Dhundukanath in *Rasendra Chintamani* written in the ninth century, on his conviction on the experimental verification of the theory to be high ideals of his time.

Saha, however, regretted. "Unfortunately for India, this high ideal was wrecked by pedants who regarded worship of ancient scriptures as the highest ideals of scholarships. Europe was also drifting to the same mess, her scholars at one time regarded the worship of Bible, Plato and Aristotle as the highest consummation of scholarship. But she was rescued out of the abyss into which she was drifting by the life-blood of Gallileo, Bruno and Kepler; unfortunately India had no martyrs of the above type for science".

His grievances were redressed and India had then the fortune to have a martyr for science by his death.

About two years before the death of Saha, his students and colleagues celebrated his sixtieth birth anniversary at Calcutta on February, 12, 1953, when a large number of scientists from India and abroad felicitated him with messages of appreciation.

On this occasion, Saha was not only paid tributes for his famous contribution in science, but also for his great services

rendered to the cause of science in the country as an Editor of *Science and Culture* and as a member of the National Planning Committee, as a member of the Governing Body of the Council of Scientific and Industrial Research and the Board of Scientific and Industrial Research.

His scientific outlook in planning be it in the field of economics, science or industry was unique for a renowned scientist of his talent and varied interests; concern for his downtrodden countrymen was always utmost in his mind. His creative genius was not only responsible for his scientific discoveries; but it induced him to rebel against the poverty and superstitions of the country and to fight those through the application of science and technology.

VI

THE MAN AND HIS PHILOSOPHY

How was Meghnad Saha as a man? A brief answer to this question can be found in the obituary of Saha written by D.S. Kothari in the *Biographical Memoirs* of the Fellow of the Royal Society (Vol.5, 1959)

Kothari writes :

"He was extremely simple, almost austere in his habits and personal needs. Outwardly, he sometimes gave the impression of being remote, matter of fact and even harsh, but once the outer shell was broken, one invariably found in him a person of extreme worth, deep humanity, sympathy and understanding; and though almost altogether unmindful of his own personal comforts, he was extremely solicitous in the case of others. He was a man of undaunted spirit, resolute determination, untiring energy and dedication."

Kothari was closely associated with Saha at Allahabad. Since he speaks of Saha from his own experiences, the above tribute may be taken as authentic and accurate. One could observe in Saha, through short interviews, his humaneness and many virtues.

Saha had so much affection for his students, that they had remained respectful to him forever. Many of his students were well established in their profession in industry, administration and other spheres of the society. Saha commanded respect from all of them.

If Saha recognised a talented student to be worthy in the sphere of research, he never encouraged him for other lucrative professions.

For instance, Saha did not permit a talented student from Orissa, working under him to give up research and to join as a lecturer in the Ravenshaw College. In fact the father of the boy, once a student of Saha, wanted his son to be with him at Cuttack. He brought the appointment letter of the DPI of Orissa and showed it to Saha. He insisted that the DPI would be aggrieved, if the appointment was not accepted and his son would never be considered for a Government job in future. In reply, Saha said 'Your DPI is known to me. I shall write to him that your son will join as a professor there after he gets his Ph.D degree". Consequently, the boy continued research. Saha had always been right in recognising the worth of a worthy researcher. At present, the said student T.P. Das is a well known professor in a renowned university in the U.S.A.

For a student, wishing to pursue a research career in a line other than his own, he did the needful. R.C. Majumdar and D.S. Kothari at Allahabad were such examples, for whom he did his best for their training abroad and also helped them to secure suitable jobs.

For one of his students namely Manoj Kr. Banerjee working in nuclear physics under him, Saha arranged postdoctoral training in the U.S.A. and earmarked a position for him in his institute. The said student, after the death of Saha, joined the institute and organised the Theoretical Nuclear Physics Division of the institute. At present, he is a distinguished professor in a renowned university in the U.S.A.

In his time, Saha had to face the scarcity of funds for arranging scholarships for his students. Some used to work without scholarships and a few obtained them from their respective State Governments. However, the payments were invariably irregular in such cases.

Such events in Saha's life, bore evidence of his affection towards his students. Saha used to help even those students who were reluctant to continue their studies in the post-graduate classes by

recommending them for jobs.

In spite of his deep involvement with serious scientific work, Saha had a fine sense of humour, which would reveal itself in the lighter moments.

Once at Allahabad, Acharya P.C. Ray wanted to use Saha's car to go around the city after lunch. This was nothing new and Ray was a frequent visitor to Saha's house at Allahabad. This time when Ray after lunch made haste for the car, Saha politely smiled and told him "Sir, what will you do with a car, I have asked for a bullock cart for you." Both Saha and Ray burst into laughter on this comment. Not to mention, very often both of them, the teacher and the student, used to discuss on the utility of Khadi and Charkha without any conclusion. Saha used to compare these movements to the cult of the bullock cart.

On Khadi movement differences between Saha and Ray were well known to the people. When Saha was asked why he was against his teacher contrary to the Indian tradition, Saha, in reply, cited the example of Yagnavalka, who had differences with his teacher, Vaishampayana, author of *Krishna Yajurbeda*, in teaching and interpretation of the same. The teacher angrily asked Yagnavalka to give back the knowledge received from him. As the myth goes, Yagnavalka vomitted the knowledge, which was eaten by Tittira birds (Partridge) and was later on reproduced as the Taittiriya Samhita of the school of Krishna Yajurbeda. Thus Yagnavalka instituted a new school of knowledge known as Sukla Yajurbeda.

Saha considered it to be the true scientific spirit, when pupils differ from their teacher, in case his teaching does not help in advancement of knowledge. Saha held that the scientific spirit of India was hindered in the past because the pupils blindly followed the tenets of the teacher. It may be mentioned in passing, that Acharya

P.C. Ray also held similar views as Saha and had blamed the Vedanta philosophy as being responsible for hindering the scientific spirit of India.

In fact, Acharya Ray had opposed the Khadi movement as being anti-science till 1922, when he was converted to it. The underlying reason for the conversion might be that afterwards he was convinced of the role of Khadi movement at least in integrating India as a nation. Saha had ignored that role totally.

However, in spite of the differences both shared a warm relationship. Saha was the secretary of the organising committee formed to raise funds to commemorate the eighty first birth anniversay of Ray. In fact, Saha was greatly influenced by Ray in all his social activities and inherited his intense love for the nation.

Saha was popular among the masses and so could win the seat in the parliament with a large majority. People, other than scientists also held him in great reverence.

There was an instance of how an unknown foreigner paid his tribute to Saha on a trivial occasion. In 1954, Saha placed an order for shaping a two-ton magnet for a mass spectrometer for his institute in the Garden Reach workshop. The order was open and the workshop sent a bill of ten thousand rupees to him as the machining cost. The Institute, then, was running short of funds. On receiving the bill, Saha phoned Mr. Lethart, the then Deputy General Manager of the shop, an Englishman, requesting him to reduce the amount in the bill. Mr Lethart asked "What amount will suit you professor?" Saha came down to 5,000 rupees to which Mr Lethart gladly agreed.

Afterwards Mr Lethart told a research worker, connected with the work, "I have no personal acquaintance with professor Saha, but I know him, I respect him. We could do the work free of cost, if Saha wanted so. However I will soon return home and hope that Saha will

be able to build a laboratory similar to the one in Harwell. Convey my best wishes to him."

Saha, like any other man, was responsive to joy and sorrow, but he was, in Kothari's words, a man of undaunted spirit, resolute determination, untiring energy and dedication.

Saha had no specific choice between U.S.A or erstwhile U.S.S.R in borrowing the technical knowhow for his country. But, in the interest of science, he had not spared any government from his bitter criticism, when such an occasion arose.

In 1935, when the Russian scientist Kapitza working in the Cambridge laboratory in U.K. went on leave to Russia, the U.S.S.R. Government did not permit him to return to Cambridge. S. Chandrashekhar from Cambridge in a letter dated 29, April, 1935, requested Saha to exert his influence through the National Institute of Science, India, to press upon the U.S.S.R. Government for the release of Kapitza. Saha at once acted accordingly and wrote an unsigned article in *Science and Culture* (Vol 7, p 35) strongly criticising the detrimental attitude of the U.S.S.R. Government towards the scientific community. Chandrashekhar, later on, congratulated Saha for his said article. Saha also criticised America against its policy of maintaining secrecy in the Atomic Energy programme. To answer the question why a scientist has taken to politics, Saha wrote in the preface of the booklet *Rethinking Our Future* :

"Scientists are often accused of living in the 'Ivory Tower' and not troubling their mind with realities and apart from my association with political movements in my juvenile years, I had lived in ivory tower upto 1930. But science and technology are as important for administation now-a-days as law and order. I have gradually glided into politics because I wanted to be of some use to the country in my own humble way."

Saha's scientific outlook was the basis of his humble way to serve the country. Though he was basically a theoretician, he could establish his potential in experiments on ionospheric research, nuclear physics, nuclear induction, biophysics etc. He envisaged the importance of Big science to which the world was gradually advancing. In initiating the Cyclotron project at Calcutta he was a pioneer of Big science in India. He seeded in India many reseachers in modern science and technology and built the ground for progress of the country through industrialisation.

Many of his plans on science and technology were nipped in the bud due to adverse situations which were created because of his uncompromising attitude and strong idealism.

For his urge of idealism, he was expelled from Dacca Collegiate School and lost his scholarship. He did not compromise to compensate his loss. He could not get a Government service because of his association with revolutionaries, that loss could not defeat him in his struggle for life.

In the last years of his life, he entered in politics with an aim to improve the conditions of science and the scientists in the country and to promote the social consequences of science through proper planning. Of course, he did not align with any political party of India for this purpose.

Saha was aware of the events of the contemporary world. In 1950, Joliot Curie had to resign from the French Atomic Energy Commission for political reasons. It was known to him that Atomic Energy programmes of all countries were being controlled by the respective Governments. He had no doubt that India had to follow the same course. Saha never did wish to join any government project, where independent research facilities of universities did not exist. Because of this, he had to keep himself aloof from the Atomic Energy

Programme of the country, though he was a pioneer in Atomic researches in India.

It so happened that he had to leave Calcutta University and there were indications that his Institute of Nuclear Physics had to sustain on Government grants. Evidently it was expected that some control over his Institute would be imposed by the Government along with the financial grant. Some of his future plans like the Synchrotron project, the Institute of Medical Science, the Research Reactor project and the Geophysics Institute etc. were not approved by the Government. Consequently, his talent and organising capability could not be fully utilised by the country. India had thus been deprived of the opportunity, where Saha could play a more efficient role.

His role in active politics was for a short duration. By that he became more popular in the society. He was an ideal man in the society of scientists and the young people.

He played a prominent role in popularising science in India. Most of his scientific articles were meant for the common people. All the activities of Saha involved his profound intellect and deep insight which helped him to travel a long way from village Seoratali to Delhi.

Saha had a clear idea about the social atmosphere of the country which he would directly express without hesitation. In the name of religion, he could not bear with the casteism, untouchability and superstitions, which made him rebel against the society of his time.

Meghnad Saha was born in an unknown family of East Bengal, but had become a symbol of freedom and progress in his lifetime. Even at the time when his contemporaries were succumbing to their own interests, Saha did not bow down to any authority for his personal benefit. In his time, the number of scientists was negligible,

but Saha, alone had firm determination to develop a modern India through his personality, talent and organising ability. In finding the direction for economic and industrial development of the country, he was above the debates between the conservatives and the moderates in the national congress, dreamt of a progressive India and wished to fulfil his dream. In this respect, his patriotism had no parallel.

He was born in an underdeveloped country much ahead of his time. His contemporary countrymen were not capable of accepting his progressive ideas and outlook. Yet, in an adverse situation, he made glorious contributions in the world of science and for the uplift of his country.

Saha will be remembered for many years to come for his unique influence on the foundation of science and technology of India today. Saha desired the progress of the country to come in a forced march. But he ignored the difficulties in executing his plans in a democratic set up of the country. He had been active in many fields and had none with him for completeing his works. In all his activities, he was a lone traveller. His colleagues were so much dependent upon him that none thought of following up his activities independently and in his absence.

He, himself, outlined the first five year plan of the institute and went to Delhi in spite of his illness. None could guess that it would be his last journey.

Saha had profound knowledge of many subjects namely Archeology, Physics, History, Economics, Social Science etc. which gained him friends in a large number in India and abroad.

Saha Memorial Lectures instituted by the Saha Institute of Nuclear Physics since 1957 had been delivered by many renowned scientists like Spencer Jones, Haldane, Janossy, Bohr, Chandrasekhar and many others who paid their glowing tributes to Saha in their deliberations.

Saha had inherited the legacy of the Indian Renaissance of the nineteenth century. But he was unique in the sense that he was the precursor in India of the new age of science which emerged in the world of twentieth century.

He was pioneer in bridging the East with the West but deeply rooted in Indian culture. Saha died the death of a martyr, but for his glorious life and work remains immortal in the hearts of the people of India.

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APPENDIX - A

LIFE - SKETCH IN BRIEF

1893: Born of a lower middle class family, the fifth child of Jagannath Saha and his wife, Bhubaneswari, in the village of Seoratali, 45km away from Dacca in erstwhile East Bengal (now the capital of Bangladesh), on 6 October.

1905: Stood first in the Dacca division in the Middle School Examination from a school in the village of Shimulia, and obtained a scholarship. Joined Dacca Collegiate School, from which he was expelled soon afterwards because of his participation in a nationalist demonstration.

1909: Appeared at the Entrance Examination from Kishorilal Jubilee School and stood first among all the condidates from erstwhile East Bengal.

1911: Stood third in the I.Sc. Examination from Dacca College, and joined the Presidency College in Calcutta.

1913: Stood second in the B.Sc. Examination, with honours in mathematics, from the Presidency College. Participated in the relief work for the people afflicted by flood in the river Damodar.

1915: Stood second in the M.Sc. Examination in mixed mathematics from the Presidency College.

1916: Joined the University of Calcutta as Lecturer in the Mathematics Department, and got himself transferred to the Physics Department a few months later.

1917: Published his two first research papers in two renowned journals, namely, *Philosophical Magazine* and *Physical Review.*

1918: Obtained the D.Sc. degree from the University of Calcutta on the basis of his thesis on radiation pressure and electromagnetic theory. Published, jointly with his colleague S.N.Bose, English translations of a few articles on the theory of relativity by A.Einstein and H. Minkowski, written in German. These were the first English translations of these remarkable articles and were published by the University of Calcutta in book form with an introduction by P.C.Mahalanobis, a member of the faculty of the Presidency College.

1920: Put forward his famous theory of thermal ionization and demonstrated its important applications in the field of astronomy, which led to the foundation of modern astrophysics. Communicated from Calcutta a series of four papers in the subject to the *Philosophical Magazine*, two of which entitled 'Ionization in the Solar Chromosphere' and' Elements in the Sun' were published in the same year. Proceeded to Europe on obtaining the Ghosh Travelling Fellowship, and joined A.Fowler's laboratory in the Imperial College of Science and Technology in London.

1921: Withdrew the fourth paper of the series of four papers communicated from Calcutta, revised it and published it under the title, 'On a Physical Theory of Stellar Spectra' in the Proceedings of the Royal Society, while the third paper entitled 'On the Problems of Temperature Radiation of Gases' had, in the mean time, been published in the *Philosophical Magazine*. Met eminent scientists like J.J.Thomson, A.S.Eddington and E.A.Milne in Cambridge. Joined W.Nernst's laboratory in Berlin in February and carried out preliminary work on the experimental verification of the theory of thermal ionization. Had discussions with renowned scientists like A. Einstein, M.Planck and M. von Laue in Berlin. Gave an invited talk

in Munich at the request of A.Sommerfeld. Returned to India on an invitation from A.Mukherjee, the then Vice-Chancellor of the Calcutta University, to accept the post of Khaira Professor in the Physics Department, and joined the University in November.

1922: Participated under the leadership of Acharya P.C. Ray, in the relief work for the flood-stricken people in North Bengal.

1923: Joined the University of Allahabad as the Professor and Head of the Physics Department.

1926: Presided over the Mathematics and Physics Section in the Session of the Indian Science Congress held in Bombay.

1927: Had the distinction of being elected a Fellow of the Royal Society (FRS). Visited many laboratories in Europe. Took part in an expedition in Norway on the occasion of a total solar eclipse on 29 June. Attended an International Congress on Physics held at Como, Italy in September on the occasion of the Death Anniversary of A. Volta.

1931: Founded the U.P. Academy of Sciences (renamed later as National Academy of Sciences) at Allahabad. Wrote, jointly with B.N. Srivastava, the renowned text-book entitled *A Text-book on Heat*, which was later renamed *Treatise on Heat*. Started fabricating a demountable vacuum furnace, with financial assistance from the Royal Society of London, for experimental verification of the theory of thermal ionization.

1933: Founded the Indian Physical Society at Calcutta.

1934: Elected General President of the Indian Science Congress Session held in Puna. Carried out important research on beta-ray activity in the field of nuclear physics. Wrote, jointly with N. K. Saha, a text-book entitled *A Treatise on Modern Physics*.

1935: Founded National Institute of Science at Calcutta (transferred later to Delhi and renamed Indian National Science Academy). Established the Indian Science News Association, and also edited its journal, *Science and Culture*.

1937: Elected Overseas Fellow of the Carnegi Trust of the British Empire. Made an extensive tour of the United States of America, Germany and England. Emphasised correctly the need of a stratosphere solar observatory in a lecture delivered in a special convocation of the Harvard University. Attended an important conference on nuclear physics at Copenhagen. Initiated research on ionospheric wave propagation at Allahabad.

1938: Joined the University of Calcutta as Palit Professor in the Physics Department. Nominated as a Member of the Planning Committee set up by the Indian National Congress. Acted as the Chairman of the Sub-committees on 'Power and Fuel' and 'Technical Education'.

1939: Published thought provoking articles, in Bengali, on modern science vis-a-vis Hindu religion in the magazine *Bharatbarsa*.

1940: Introduced nuclear physics in the M.Sc. physics syllabus of the Calcutta University. Initiated research on nuclear physics and cosmic rays at the Palit laboratory in the Physics Department. Initiated steps for building a cyclotron, the first of its kind in the country, around which nuclear physics could grow.

1944: Visited U.K., U.S.A. and Canada as a Member of an Indian Scientific Mission. Published a valuable article in the*Science and Culture*, laying the foundation of the Damodar Valley Project in the context of river management in India.

1945: Represented the Government of India in the Annual

Function of the Soviet Academy of Science, held in Moscow.

1946 : Elected as the President of the Governing Council of the Indian Association for the Cultivation of Science and also as the President of the Asiatic Society.

1947 : Deeply involved in the problem of rehabilitation of the refugees from erstwhile East Pakistan.

1948 : Nominated as a member of the Education Commission set up by the Government of India. Encouraged research on biophysics and construction of an electron microscope (the first of its kind in India) in his laboratory.

1950 : Founded the Institute of Nuclear Physics at Calcutta, which was opened by Madame Irene Joliot-Curie on 11 January.

1951 : Became the honorary life-long Director of the Institute of Nuclear Physics in the University of Calcutta while he was still the Palit Professor in the University of Calcutta. (The Institute was named Saha Institute of Nuclear Physics after his demise as a token of respect to his memory).

1952 : Elected Member of the Parliament as an independent candidate from the North-West Calcutta constituency. Nominated as the Chairman of the Calendar Reform Committee set up by the Government of India.

1953 : Retired from the University of Calcutta. Joined the Indian Association for the Cultivation of Science as its Director.

1954 : Presented the Indian proposal for World Calendar reform in the 18th session of the UNESCO held in Geneva.

1956 : Collapsed and died suddenly on the way to the office of the Planning Commission in Delhi on 16 February.

APPENDIX - B

SCIENTIFIC PAPERS OF MEGHNAD SAHA

For full text refer to the Collected Scientific Papers of Meghnad Saha published by Council of Scientific and Industrial Research, New Delhi, 1969.

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On a New Theorem in Elasticity :*Jour Asia Soc. Bengal,* New Sr. **14**, 421 1918.

On the Pressure of Light (with S. Chakraborty) : *Jour Asia. Soc. Bengal, New Sr.* **14**, 425, 1918

On the Dynamics of the Electron : *Phil. Mag., Sr.* VI, **36**, 76, 1918.

On the Influence of the Finite Volume of Molecules on the Equation of State (with S.N. Bose) : *Phil. Mag., Sr.* VI, **36** 199, 1918.

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Ionisation in the Solar Chromosphere : *Phil. Mag., Sr.* VI, **40** 472, 1920

Elements in the Sun : *Phil. Mag., Sr.* VI, **40**, 809, 1920

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The Atomic Radius and the Ionization Potential : *Nature,* **107**, 682, 1921

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On an Active Modification of Nitrogen (with N.K. Sur) : *Phil. Mag., Sr.* VI, **48**, 421, 1924

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Ultimate Constituents of Matter - 12, 1935
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VOL. II (1936-37)

Conference on Nuclear Physics - M.N. Saha and P.L. Kapur-133, 1936.
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Industries and Scientific Research (Ed. Art.) - 413, 1937.
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VOL. III (1937-38)

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Obituary of Lord Rutherford of Nelson-M.N. Saha and D.S. Kothari 300, 1937.
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Minor Planets (unsigned) - 312, 1937
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